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MEASUREMENTS OF THE FLYING QUALITIES OF A HAWKER HURRICANE AIRPLANE

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NACA

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MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

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INTRODUCTION

At the request of the Army Air Corps the flying qualities of a Hawker Hurricane airplane were investigated. The tests were conducted at Langley Field, Va., during the period from November 25, 1941, to December 28, 1941. Thirteen flights and approximately 17 hours of flying time were required to complete the tests, which included extensive measurements of stability, controllability, and stalling characteristics.

These tests of the flying qualities of the Hawker Hurricane were, in general, similar to tests of other pursuit airplanes previously made by the National Advisory Committee for Aeronautics.

DESCRIPTION OF THE HAWKER HURRICANE AIRPLANE

The Hawker Hurricane is a single-place, single-engine, low-wing, cantilever monoplane with retractable landing gear and partial-span split flaps (figs. 1, 2, 3, and 4). The general specifications of the airplane are as follows:

Name and type	Hawker Hurricane II (Air Ministry No. Z2963)
Engine	Rolls-Royce Merlin XX
Ratings:	
Take-off	1300 hp at 3000 rpm
Normal	1255 hp at 2850 rpm at 10,000 ft
Maximum, low blower	1270 hp at 3000 rpm at 12,250 ft
Maximum, high blower	1185 hp at 3000 rpm at 21,000 ft
Gear ratio	0.477:1
Propeller	Rotol constant speed (wood blades)
Diameter	11 ft 4 in.
Number of blades	3
Angle of thrust axis from datum	$-\frac{1}{2}^{\circ}$

Fuel capacity	94 Imperial gal
Oil capacity	$7\frac{1}{2}$ Imperial gal
Supercharger (2-speed) gear ratios	8:15 to 1 9:49 to 1
Weight (empty)	5486 lb
Normal gross weight as received	6854 lb
Weight as flown for tests	7014 lb
Wing loading (normal gross weight)	26.6 lb/sq ft
Power loading (normal gross weight)	5.46 lb/hp
Over-all height (datum line level)	12 ft 2 in.
Over-all length	31 ft 6 in.
Wing:	
Span	40 ft
Area	257.6 sq ft
Airfoil section:	
Root	Clark YH 19 percent modified
Tip	Clark YH 12.2 percent
Aspect ratio	6.22
M.A.C.	84.3 in.
Location of M.A.C. (approx.)	5.2 in. behind L.E. wing
Taper ratio	2.03:1
Dihedral (outer panels)	$+3.5^{\circ}$
Incidence with fuselage datum	$+2.0^{\circ}$, $\pm\frac{1}{2}^{\circ}$
Sweepback (L. E.)	5.1°
Wing flaps (split T.E. type):	
Total area	25.11 sq ft
Flap (semispan)	9 ft 6 in.
Travel	80° down
Ailerons:	
Length (each)	7 ft $8\frac{1}{2}$ in.
Area (total area, each)	10.2 sq ft
Balance area (each)	2.92 sq ft
Travel:	
Right	down 21.5°, up 20.6°
Left	down 19.2°, up 22.4°
Stabilizer (fixed):	
Maximum chord	2 ft 8 in.
Area (including 2.5 sq ft fuselage)	24.1 sq ft
Incidence to datum line	$1\frac{1}{2}^{\circ}$
Elevator:	
Span	11 ft 0 in.
Maximum chord	1 ft $6\frac{1}{4}$ in.
Area (behind hinge line but including horn balance)	13.0 sq ft
Travel	$\pm 26^{\circ}$
Trim tab area (total)	0.76 sq ft
Balance area (horn balances)	1.56 sq ft

Vertical fin:
- Area. . . . . 8.83 sq ft
- Offset. . . . . $1\frac{1}{2}^{\circ}$ left

Rudder:
- Vertical span . . . . 6 ft $5\frac{1}{4}$ in.
- Maximum chord behind hinge line . . . . 2 ft 3 in.
- Total area . . . . 13.06 sq ft
- Balance area (horn balances). . . . . 0.21 sq ft
- Travel. . . . . $\pm 29^{\circ}$
- Balance tab area. . . . . 0.36 sq ft
- Balance tab linkage ratio 1:1

Distance from elevator hinge to leading edge of wing. 22.1 ft

Distance from rudder hinge line to leading edge of wing. 22.55 ft

Maximum fuselage cross-sectional area (excluding radiator) approximately. . . . . 8.3 sq ft

The relation between the control-stick position and the angles of the controls is shown on figures 5 and 6.

INSTRUMENT INSTALLATION

Items measured	NACA instruments
1. Time	timer
2. Airspeed	airspeed recorder
3. Positions of the three control surfaces	control-position recorder
4. Rolling velocity	angular-velocity recorder
5. Normal, longitudinal, and lateral acceleration	three-component accelerometer
6. Angle of sideslip	recording yaw vane
7. Angle of bank or pitch	recording inclinometer
8. Rudder force	rudder-force recorder
9. Aileron and elevator force	indicating force gage on top of stick

The airspeed recorder was connected to a swiveling pitot-static head which was free to rotate in pitch but not in yaw, located on a boom extending a chord length ahead of the right wing tip. The yaw vane was located at the end of a similar boom on the left wing tip. All the recording instruments were synchronized by the timer and the records were obtained photographically. Because of the unusual control stick in the Hurricane, control forces could not be measured by the NACA control-force recorder. Instead, the spade grip on the stick was replaced by a straight tube, and a visual control-force indicator which rested against this tube was used by the pilot.

The instrument recording the angles of the three control surfaces was attached to the control linkages near the cockpit. Tests made on the ground showed that errors in the recorded angles caused by stretch in the control system were small enough to be negligible.

AIRSPEED CALIBRATION

The readings of the pilot's meter compared with the correct indicated airspeed with flaps up or down are plotted in figure 7. The correct speed was determined by flying in formation with the Brewster XSBA-1 airplane. The calibration of the airspeed recorder in the latter airplane was made by the use of a trailing airspeed head. The installation of the airspeed indicator in the Hurricane consisted of a pitot-static tube located below the left wing, slightly ahead of the aileron hinge. This installation gave small errors, especially at low speeds.

TESTS, RESULTS, AND DISCUSSION OF RESULTS

All the flying qualities tests were made with the center of gravity at a distance of 28.06 inches behind the leading edge of the wing. The mean aerodynamic chord was found from measurements taken on the airplane to be 84.3 inches in length, located 5.2 inches behind the leading edge of the wing center section. If these values are used, the center of gravity is found to be at 27.1 percent of the mean aerodynamic chord. Because no accurate drawings of the Hurricane were available, the values calculated for the mean aerodynamic chord may be somewhat in error.

The center of gravity of the airplane with full military load, before the addition of NACA instruments, was found to be at 27.8 inches behind the leading edge of the wing, or 26.8 percent of the mean aerodynamic chord. Though no figures are available as to the allowable center-of-gravity locations, this value is believed to represent closely the condition in which the airplane is normally flown. The weight of the airplane in this case was 6854 pounds. After the addition of NACA instruments and ballast necessary to retain approximately the same center of gravity for the tests, the weight was increased to 7014 pounds.

LONGITUDINAL STABILITY AND CONTROL

Characteristics of uncontrolled longitudinal motion.- Of the two types of control-free longitudinal oscillation, only the short-period oscillation was investigated with the Hurricane as previous research work has shown that the well-known long-period (phugoid) oscillation has little or no correlation with the ability of pilots to fly an airplane efficiently.

The degree of damping of the short-period oscillation was determined by deflecting the elevator and quickly releasing it at high speed. In all cases the subsequent variation of normal acceleration and elevator angle had completely disappeared after one cycle, thereby satisfying the requirement for this condition suggested in reference 1.

Characteristics of elevator control in steady flight.- The characteristics of the elevator control of the Hawker Hurricane airplane in steady flight were measured by recording the elevator positions and forces required for trim at various airspeeds. These measurements were made in the following conditions of flight:

Flight condition	Manifold pressure (in. Hg)	Engine speed (rpm)	Flap position	Landing-gear position	Radiator-shutter position	Hood position
gliding	throttle closed	----	up	up	closed	closed
climbing	42 (6 lb/ sq in. "boost")	3000	up	up	$\frac{1}{2}$ open	closed
landing	throttle closed	----	down	down	closed	open
wave-off	38(4 lb/ sq in. "boost")	2800	down	down	open	open

The results of these tests are presented in figures 8 and 9 and may be summarized as follows:

1. In all of the conditions except the climbing condition, a small degree of stick-fixed static stability existed, as shown by the

negative slopes of the curves of elevator angle against airspeed. Only in the climbing condition (flap up, power on), in which longitudinal instability existed between 100 and 150 miles per hour, did the airplane fail to meet the requirement of reference 1.

The variation of elevator angle with angle of attack $\frac{\partial \delta_e}{\partial \alpha}$ in the gliding condition was 0.16, a smaller value than is usually considered desirable. In spite of this small degree of static stability in the gliding condition, the airplane displayed stick-fixed static stability in the flap-down condition of flight with power on. The highest degree of static stability was obtained in the landing condition (flaps down, power off).

2. The variation of stick force with airspeed was very small in all conditions of flight. In the gliding condition, the variation of stick force with airspeed was slightly stable over most of the speed range. In the climbing condition, an unstable region existed between 115 and 150 miles per hour. Stability existed in the wave-off condition. This fact is surprising because, in the landing condition (flaps down, power off), the stick-force gradient became unstable at low speeds. It will be noted that the airplane failed to meet the requirement for a stable stick-force gradient, stated in reference 1 at low speeds in the landing condition, and over part of the speed range in the climbing condition.

3. The elevator-control forces were too small in most cases, to return the control to its trim position, because of the large amount of friction in the elevator-control system. The friction as measured in flight amounted to ±3 pounds, which means that a force of 6 pounds was necessary to reverse the motion of the stick. The stick-free stability of the Hurricane is therefore in reality stick-fixed stability and depends on the slopes of the curves of elevator angle against airspeed. Because the stability indicated by these curves, especially with flaps up, is very small, the airplane was difficult or impossible to trim at most speeds. Because the friction in the system masked the elevator forces required for trim at a given speed, it was possible for the pilots to obtain erroneous impressions of the degree of longitudinal stability that existed.

4. The elevator angles required for trim were well within the available range in all conditions.

Characteristics of the elevator control in accelerated flight.- The characteristics of the elevator control of the Hawker Hurricane airplane in accelerated flight were determined from measurements taken in abrupt pull-ups from straight flight and in rapid 180° turns. Time histories of representative turns are presented in figures 10 to 15.

LATERAL STABILITY AND CONTROL

Characteristics of uncontrolled lateral and directional motion.- Because of the lack of time available for the tests, no measurements of the uncontrolled lateral oscillation of the Hurricane were conducted. No undesirable short-period oscillations of the rudder or aileron controls were noted.

Aileron-control characteristics.- The effectiveness of the ailerons of the Hawker Hurricane airplane was determined by recording the rolling velocity produced by abruptly deflecting the ailerons at various speeds. The aileron angles and stick forces were measured. The results of these tests are presented in figures 18, 19, 20, and 21. Figure 18 shows the variation of $pb/2V$ and aileron force with total aileron deflection in the landing condition, and figure 19 shows these curves for level flight with flaps and gear up. The quantity $pb/2V$ is the helix angle in radians described by the wing tip in a roll, where p is the rolling velocity in radians per second, b is the wing span in feet, and V the velocity in feet per second. Total aileron angle is the sum of the deflections of the right and left ailerons.

The ailerons were unusually light for small deflections. The force increased linearly with deflection to about two-thirds maximum aileron deflection. After this point it increased much more rapidly. The effectiveness of the ailerons also varied linearly with deflection up to a certain point, but beyond about two-thirds maximum aileron deflection it increased much less rapidly. This increase of stick force and decrease in effectiveness at large aileron deflections is believed to be caused by separation of the flow on the lower surface of the upward deflected aileron at large deflections. This separation destroys the balancing effect of the projecting Frise balance and also reduces the rolling moment given by the aileron.

Figure 20 shows the aileron deflection, stick force, and helix angle obtained in a series of rolls at various speeds intended to represent the maximum rolling velocity which could be readily attained. The pilot, while using the control-force indicator, could not exert more than about 45 pounds on the stick. With this force full deflection could be obtained only up to a speed of about 140 miles per hour. The rapid increase of stick force near maximum deflection prevented full motion of the stick at greater speeds.

Another method of presenting the results of the aileron roll measurements is that given in figure 21, which shows the variation of aileron force with speed for different rolling velocities. It is interesting to note that the force required to attain a rolling velocity of 0.6 or 0.8 radian per second decreased as the speed was increased from 100 to 200 miles per hour. This unusual condition results from the rapid increase of stick force near maximum deflection. A very small force was sufficient to attain a rolling velocity of 0.4 radian per second, even at 300 miles per hour. For purposes of ordinary flying, therefore, the pilots regarded the ailerons as very light and responsive. The very small friction ($\pm \frac{1}{2}$ lb) in the system contributed to this impression. In order to obtain a high rate of roll, however, excessively high forces had to be applied to the stick. For example, at 190 miles per hour, a force of 20 pounds to the left produced a rolling velocity of 1.02 radians per second or a $pb/2V$ of 0.066, whereas doubling this force increased the rolling velocity to only 1.10 radians per second or to a $pb/2V$ of 0.071.

The ailerons failed to meet the requirement of reference 1 which states that a value of $pb/2V$ of 0.07 should be attained with a stick force of 30 pounds at eight-tenths of the maximum indicated speed in level flight or 215 miles per hour in this case. Values of 0.061 for $pb/2V$ in left rolls and 0.056 in right rolls were obtained under these conditions. The ailerons were considered by the pilots to be insufficiently effective for maneuvers requiring high rolling velocities.

Yaw due to ailerons.- The maximum sideslip angle, caused by full deflection of the ailerons in level flight at 100 miles per hour with the rudder fixed, was 12°. This speed is the lowest at which the tests were conducted. Indications are, however, that the Hurricane airplane would meet the requirement of reference 1 which states that the maximum sideslip developed at 110 percent of minimum speed as a result of full aileron deflection should not exceed 20°. The sideslip developed as a result of aileron deflection did not reduce the rolling velocity because of the lack of dihedral effect on this airplane.

Rolling moment due to sideslip.- The rolling moment due to sideslip was measured by recording the aileron angles required in steady sideslips. These measurements were made at various speeds in the climbing, gliding, and landing conditions. The results of the sideslip measurements are presented in figures 22-28 in which the rudder, elevator, and aileron angles, angle of bank, and rudder force are plotted as functions of the sideslip angle. These figures may be somewhat in error because the existence of angularity of the flow at the yaw vane may cause the recorded sideslip angle to differ slightly from the angle of the thrust axis. The fact that the recorded value of the sideslip was zero for the trim condition of zero bank with power off indicates that the error was small in this case. In power-on flight, the airplane was known to sideslip to the left at zero bank, as is shown on the curves. The exact value of sideslip may, however, be somewhat in error. The absolute values of rudder force may be in error by ±10 pounds because of unknown changes in the zero reference of the recorder. In all cases the slopes of the curves of the plotted quantities are correct.

The rolling moment due to sideslip (dihedral effect) was measured by the amount of aileron movement required to offset the rolling tendencies of the airplane. The results show that in the climbing condition (flaps up, gear up, full power) an appreciable amount of right aileron had to be applied in sideslips to the left. This condition indicated a negative dihedral effect and failed to satisfy the requirements of reference 1. The dihedral effect was also slightly negative in sideslips to the right. In the gliding condition (flaps up, gear up, power off) the dihedral effect was in the correct direction but it was very slight. In the landing condition (flaps down, gear down, power off) the dihedral effect was practically neutral at 85 miles per hour but was slightly negative at 120 miles per hour. Though no measurements were made of the aileron forces in sideslips, they were observed to be in the unstable direction in the conditions where the dihedral effect was negative.

Further data concerning the dihedral effect of this airplane were obtained in measurements of abrupt rudder kicks (figs. 29 and 30). The rolling velocity resulting from rudder kicks was practically zero in all conditions, though when it did occur it was in the correct direction. Apparently the rolling moment due to yawing velocity was sufficient to offset the negative dihedral effect obtained in steady sideslips. The rolling velocity was so slight that in rudder kicks to the right the leading wing dropped because of the combination of yawing and pitching downward which occurred. Thus the pilot obtained the impression of instability in rudder kicks to the right even though the airplane did not roll about its longitudinal axis.

Rudder-control characteristics.- The rudder-control characteristics were investigated in steady flight, in sideslips, and in abrupt rudder kicks. In the rudder-kick maneuvers, records were taken of rudder position, rudder force, rolling velocity, sideslip angle, and normal acceleration resulting from abrupt deflections of the rudder while the the other controls were held fixed. Figure 29 shows the results of rudder kicks in the landing condition at 81 and 122 miles per hour, and figure 30 shows the results for level flight at 99, 121, and 240 miles per hour.

The maximum sideslip obtained by abruptly deflecting the rudder was only slightly greater than the angle reached in a steady sideslip with the same rudder deflection. Slightly larger angles of sideslip were obtained in the flap-up conditions of flight than in the flap-down conditions; this situation indicates that the directional stability was smaller or the rudder effectiveness greater with flaps up. Because the maximum sideslip angles reached in rudder kicks were larger than those attained in aileron rolls at low speeds, the rudder is believed to be sufficiently powerful to overcome the adverse yawing moment that occurred in aileron rolls.

The rudder angles required from trim in straight flight were well within the available range in all conditions, as is shown in figures 8 and 9. The limit of rudder travel (29°) was most closely approached in the wave-off condition, in which a deflection of about 18° was needed at the stall. As will be discussed later, the rudder forces were rather heavy. Inasmuch as no trim tab was available on the rudder, considerable effort was required for the pilot to hold a large rudder deflection for trim.

As is shown in figure 17, the slight tendency to turn to the left in a tail-high take-off was easily counteracted by the rudder. In tail-low take-offs this yawing tendency did not occur, and in any case it was much smaller than has been encountered on previously tested airplanes of comparable design.

The rudder control, in conjunction with the brakes, was adequate to maintain directional control in landing, as is shown in a time history of a three-point landing (fig. 16). As will be mentioned in connection with the discussion of stalling characteristics, no undesirable ground-looping tendencies were noted on this airplane.

The effectiveness of the rudder in recovering from spins was not investigated.

The rudder forces plotted in figure 29 and 30 were the initial forces required to deflect the rudder. They are seen to be heavy even at low speeds. As soon as the yawing velocity and sideslip angle had built up, however, the rudder forces decreased to about one-third of the plotted values because of the floating tendency of the rudder. In no case, however, was a reversal of the rudder force experienced. The requirement of reference 1 concerning reversal of rudder forces was therefore satisfied. A force greater than 180 pounds would be required to deflect the rudder fully even at the minimum speed of the airplane. Because the maximum rudder deflection was not required in meeting any of the rudder-control requirements which were investigated, these requirements could all be fulfilled with a force of less than 180 pounds.

A force of 12 pounds was required to reverse the motion of the rudder pedal in order to overcome friction in the rudder system. Because of the small variation of rudder force with sideslip angle, which will be discussed further in the following section, this friction was sufficient to hold the airplane at a fairly large angle of sideslip. This tendency proved annoying to the pilots.

No measurements were made of the rudder forces required for trim in high-speed dives.

Yawing moment due to sideslip.- As shown in figures 22 to 28, right rudder was always required for right sideslip and left rudder for left sideslip. This fact indicates that the airplane, with rudder fixed, was directionally stable in all conditions of flight. The slope of the curve of rudder angle against sideslip was slightly greater at large angles of sideslip than at small ones. It has been previously stated that the directional stability was sufficient to restrict the yaw due to ailerons to the specified value.

The curves of rudder force against angle of sideslip (figs. 22-28) show that the directional stability with rudder free was small, especially at small angles of sideslip. The slope of the curve never became unstable, however. The small variation of rudder force with sideslip angle is attributed to the floating tendency of the rudder equipped with a balance tab. At large rudder deflections, the balance tab was less effective, causing a rapid rise in the rudder forces.

Cross-wind force characteristics.- The cross-wind force characteristics of the airplane are shown by the angles of bank required to hold steady sideslips (figs. 22-28). The angles of bank were small at low speeds, though no smaller than those obtained with other airplanes of comparable design. Inasmuch as the side force for a given sideslip varies as the square of the speed, the angle of bank required for a given sideslip likewise increases rapidly with the speed. A large side force in sideslips is desirable because the pilot finds it easier to maintain unyawed flight if a large angle of bank is required to sideslip. The pilot found it difficult in the Hurricane to maintain unyawed flight at low speeds because of the small side-force gradient and because no aileron deflection was required to sideslip.

Pitching moment due to sideslip.- The pitching moment due to sideslip is shown by the variation of elevator angle with angle of sideslip in the steady sideslip measurements (figs. 22-28) and by the variation of normal acceleration with rudder angle in the rudder kicks (figs. 29 and 30).

The airplane tended to pitch down in both left and right sideslips. The pitching moment due to sideslip was slightly larger than the requirement of reference 1 which states that less than 1° of elevator movement should be required to maintain longitudinal trim when the rudder is deflected 5°. At large angles of sideslip, the Hurricane displayed an unusually large negative pitching tendency. This tendency did not become apparent at sideslip angles less than about 5°. It does not interfere, therefore, with the ability to train the guns on a target by slightly deflecting the rudder. In sideslips of large magnitude, such as those made intentionally to lose altitude, or those caused inadvertently by the yawing moment due to rolling, the pitching tendency became very annoying to the pilots. As can be seen in figure 22, approximately 17.5° up-elevator deflection from the trim condition at zero sideslip was required with maximum right rudder deflection in the climbing condition at low speed. This elevator deflection is much larger than the range of elevator angles used for trim throughout the speed range in unyawed flight. The pitching moment due to sideslip is believed to be caused partly by the decrease in downwash on the horizontal tail when it moves from behind the center section of the wing in yawed flight. This explanation appears inadequate to account for all of the observed pitching moment. It is possible that separation of the flow at the wing root on the downwind side of the fuselage may blanket the low aspect-ratio tail surface or may even cause an upwash to act on this half of the tail, resulting in the large negative pitching tendency.

As was mentioned in connection with the cross-wind force characteristics, the pilot found it difficult to maintain unyawed flight at low speeds. Because of the pitching tendency in sideslips an inconsistent variation of angle of sideslip with speed would be expected to cause scatter in the points for the curves of rudder angle, elevator angle, and elevator force against speed. In view of this fact, the consistency of the points plotted in the static-stability measurements (figs. 8 and 9) is considered satisfactory. The scatter which does exist may be explained on this basis.

The pitching down which occurred in rudder kicks is shown by the curves of normal acceleration that are plotted in figures 29 and 30. In rudder kicks to the right, the airplane always pitched down. The intensity of the negative acceleration for a given sideslip was proportional to the speed. Inasmuch as negative accelerations caused the engine to cut out, and due to the violent nature of the pitching tendency, rudder kicks giving a change in negative acceleration greater than 1.5g were not made. At 240 miles per hour, a rudder deflection of only 4° to the right was sufficient to cause a change in acceleration of -1g.

In rudder kicks to the left, the airplane initially pitched up. At large rudder deflections, the airplane pitched down violently as soon as the sideslip angle had started to build up. For small rudder deflections, however, the airplane continued to pitch up throughout the maneuver. The initial pitching tendency of the airplane in rudder kicks was attributed partly to the gyroscopic moment of the propeller, which causes the airplane to pitch down when it yaws to the right and up when it yaws to the left. The final tendency to pitch down in rudder kicks to either side is caused by the pitching moment due to sideslip which was measured in steady sideslip tests. This effect is not very powerful until the sideslip angle exceeds about 5°. The pitching motions caused by use of the rudder are, of course, very undesirable.

Power of rudder and aileron trimming devices.- No trim tabs were provided on the rudder or ailerons and, as mentioned previously, the pilots considered the rudder forces for trim rather heavy. No measurements of rudder forces required for trim were made. The aileron forces required for trim were light because of the light forces required for small aileron deflections. The aileron angles required for trim are plotted in figures 8 and 9.

STALLING CHARACTERISTICS

The stalling characteristics of the Hawker Hurricane airplane were studied by recording the movements of the controls and the motions of the airplane in the stall approach, the stall, and in recovery. Stalls were made in the climbing, gliding, landing, and wave-off conditions of flight with the gun ports open and closed. In most cases the controls were held in their trim positions after the stall, though in some stalls control of the stalled airplane was attempted.

The records of representative stalls are presented as time histories taken from the instrument records (figs. 31-34). In no case was the stall very violent. Recovery from a stalled condition could always be accomplished by normal use of the controls. The stalling characteristics in the various conditions were determined to be as follows:

1. Gliding condition.- In the gliding condition with gun ports open, a center section flow breakdown first occurred which caused the airplane to pitch down. This motion would ordinarily serve as a stall warning. When the stick was held back, however, a left roll occurred. This roll stopped of its own accord when about 20° bank had been reached. Figure 31 shows that about the same motion occurred when the rudder was used to check the roll.

Ordinarily attempts at control resulted in a rolling oscillation of increasing amplitude. With the gun ports closed a slower left roll occurred.

2. Climbing condition.- In the climbing condition with gun ports open, there was very little tendency of the airplane to roll. The increased rearward motion of the stick near the stall, which was shown in the static stability measurements, served as a slight stall warning. As the stall was approached, a slow uncontrollable left bank and sideslip developed. With gun ports closed a tendency to pitch down was followed by a rolling oscillation of slowly increasing amplitude as shown in figure 32. The large amount of left sideslip which occurred in straight power-on flight near minimum speed is shown in this figure. This sideslip is not apparent to the pilot because it occurs while the wings are laterally level. The left side force and yawing moment on the propeller,

caused by the high angle of attack of the propeller axis, are believed to be responsible for the development of the sideslip.

3. Landing condition.- In the landing condition with gun ports open, a pitching down tendency served as warning of the stall. This was accompanied by lightening the stick force which gave the pilot the impression of longitudinal instability. A fairly rapid roll-off either to the right or left followed the initial pitching. Figure 33 shows a time history of such a stall. With the gun ports closed, the airplane showed no tendency to roll off unless the controls were used. A pitching oscillation developed after the stall in this case.

A blast of air through the cockpit on the pilot's face was noted at the stall in the landing condition. A similar occurrence has been noted to precede a ground loop on other airplanes.

Since ground-looping characteristics are closely related to the stalling tendencies of an airplane, it would be well to mention at this point that no ground-looping tendencies were displayed by the Hurricane, in spite of the afore-mentioned air flow through the cockpit. One reason for this appears to be that the ground angle was somewhat less than the stalling attitude, as was proved by the fact that tail-first landings could readily be made.

4. Wave-off condition.- In the wave-off condition, there was no tendency to roll off with the gun ports either open or closed. A slow uncontrollable left bank and sideslip developed when the stick was held back. Figure 34 shows a time history of a stall in this condition.

5. Maximum lift coefficients.- The stalling speeds and lift coefficients at the minimum speeds obtained are listed in the following table. In flight conditions where no marked roll-off occurred, the minimum speed was difficult to define and varied by as much as 5 miles per hour in different stall attempts. The values tabulated are the average stalling speeds for each condition. In some conditions only one or two stalls were made. Therefore these values may not be representative of the average stalling speeds in these conditions.

Condition	Gun ports open			Gun ports closed		
	Stalls averaged	Indicated stalling speed, mph	Maximum lift coefficient	Stalls averaged	Indicated stalling speed, mph	Maximum lift coefficient
gliding	4	89.5	1.31	1	86.5	1.41
climbing	2	74.0	1.92	1	70.3	2.14
landing	8	72.6	2.00	2	70.3	2.14
wave-off	1	66.2	2.40	2	64.2	2.54

The values appear to show a consistent increase in maximum lift coefficients of about 0.1 or 0.2 with the gun ports closed over those obtained with the gun ports open. This increase is similar to that obtained on other airplanes with wing gun installations.

As shown in the static stability measurements, an increased rearward movement of the stick was required near the stall. This motion indicates that flow separation occurred first at the center section. Buffeting caused by the stalled flow warned the pilot of the impending stall while he still had available rearward stick motion before a roll could occur. This type of stall warning was particularly valuable in preventing rolling instability in accelerated flight.

CONCLUSIONS

The flying qualities of the Hawker Hurricane may be briefly summarized in terms of the requirements of reference 1 as follows:

1. The short-period longitudinal oscillation was satisfactorily heavily damped in all conditions tested.

2. Static longitudinal stability was satisfactory except for:

a. Friction in elevator-control system which masked force gradients.

b. Instability with climbing power, flaps up, gear up at indicated airspeeds between 100 and 150 miles per hour.

c. Unstable stick force gradient in the landing condition at low speed.

3. The stick force gradient in maneuvers was 8.1 pounds per g. This exceeds somewhat the recommended upper limit for pursuit airplanes of 6 pounds per g.

4. The stick-position change with angle of attack in maneuvers was approximately 2.5 inches. This value is about 60 percent of the 4-inch stick-position change recommended in reference 1.

5. The elevator control was adequate for landing and take-off.

6. The longitudinal trim changes due to changes in engine power, flap position, or landing-gear position were desirably small.

7. The elevator tab was incapable of trimming the airplane below 140 miles per hour with flaps and landing gear down.

8. The damping of the lateral oscillation was not measured. No abnormal or undesirable characteristics were noted, however, in this respect.

9. The aileron control was adequate at low speeds but somewhat weak at high speeds. The helix angle $pb/2V$ at 0.8 maximum level flight speed was considerably below the value of 0.07 radian suggested in reference 1, unless stick forces far greater than 30 pounds were applied.

10. Aileron yaw was satisfactorily small.

11. Dihedral effect was practically zero for power-off flight or in high-speed power-on flight. At low speeds with power on, dihedral effect was definitely negative, particularly for sideslips made to the left. The requirements of reference 1 were not met in this respect.

12. The rudder was adequate for dealing with aileron yaw and for directional control in landing or take-off.

13. Directional stability was satisfactory in all conditions tested except for friction in the rudder-control system.

14. The pitching moment due to sideslip was excessive for large rudder deflections. The requirement of reference 1 which is based on the elevator correction needed for ±5° rudder was very nearly fulfilled.

15. The stalling characteristics in normal flight or in maneuvers were considered excellent. In three-point or slightly tail-first landings, rolling or yawing moments due to stalling were not evident.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 20, 1942.

REFERENCE

1. Gilruth, R. R.: Requirements for Satisfactory Flying Qualities of Airplanes. NACA Rep. No. 755, 1943.

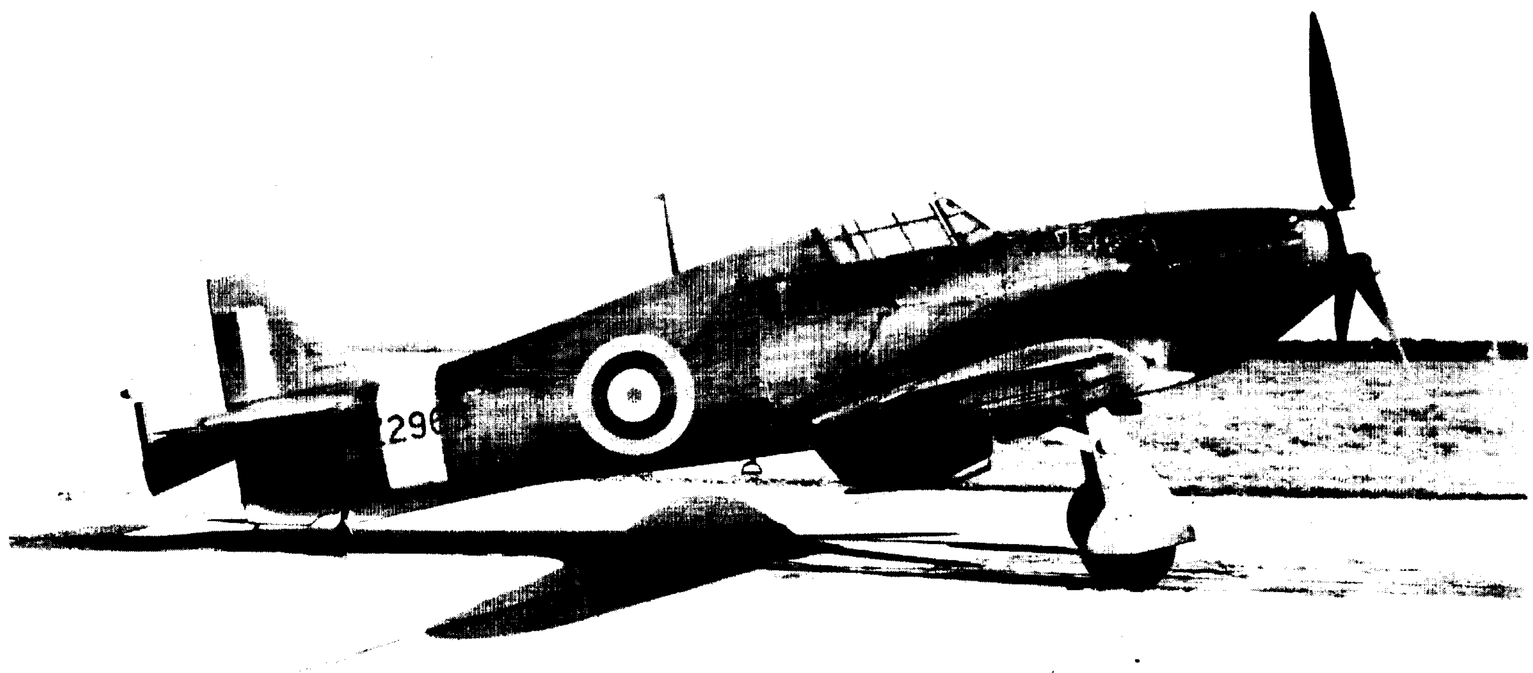

Figure 1.- Side view of the Hawker Hurricane airplane.

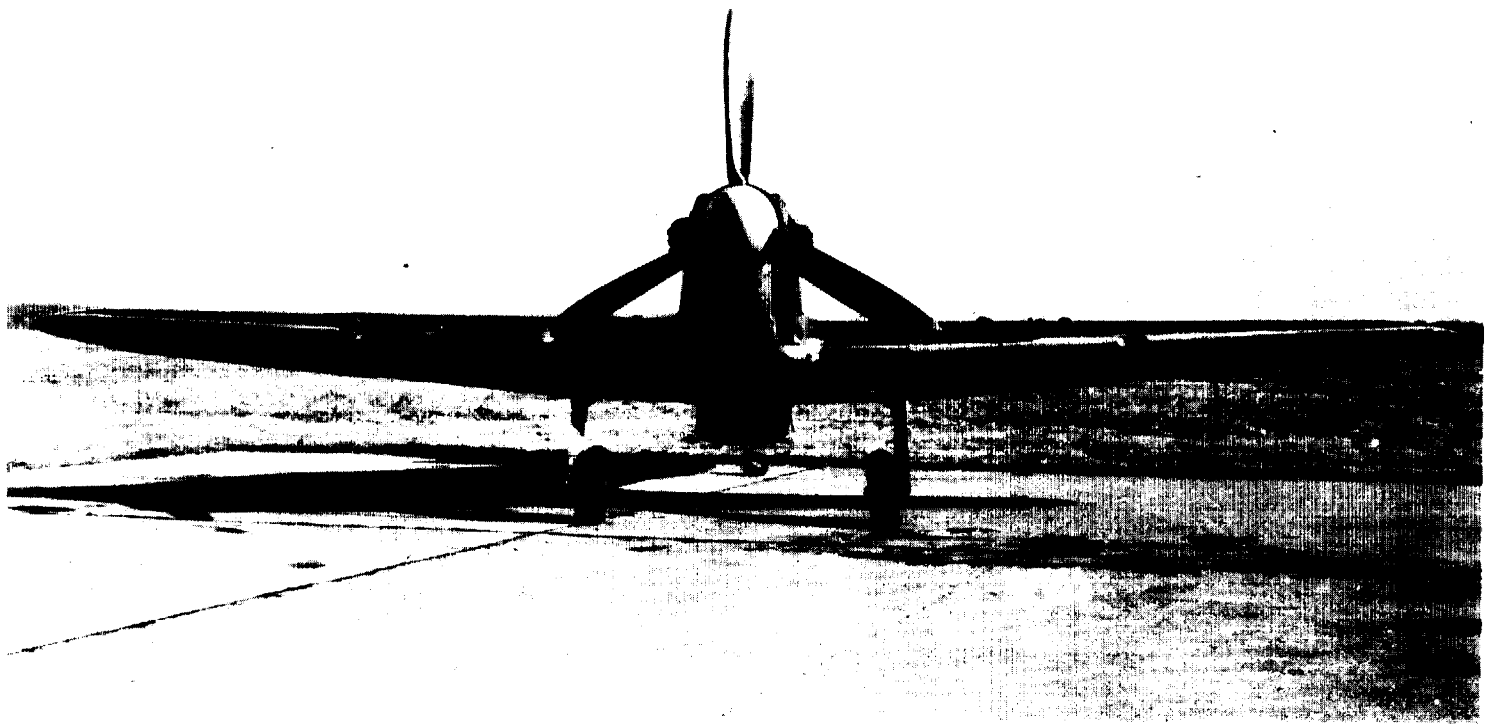

Figure 2.- Front view of the Hawker Hurricane airplane.

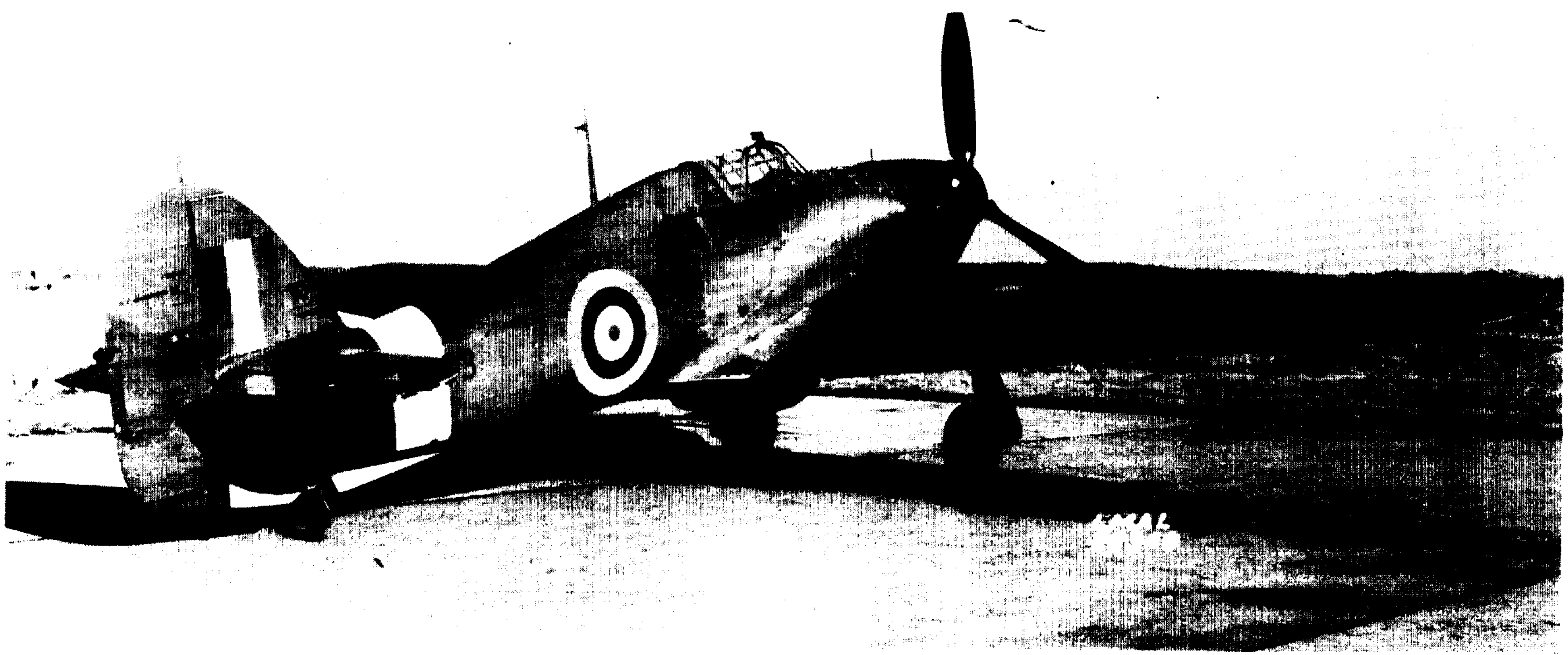

Figure 3.- Three-quarter rear view of the Hawker Hurricane airplane.

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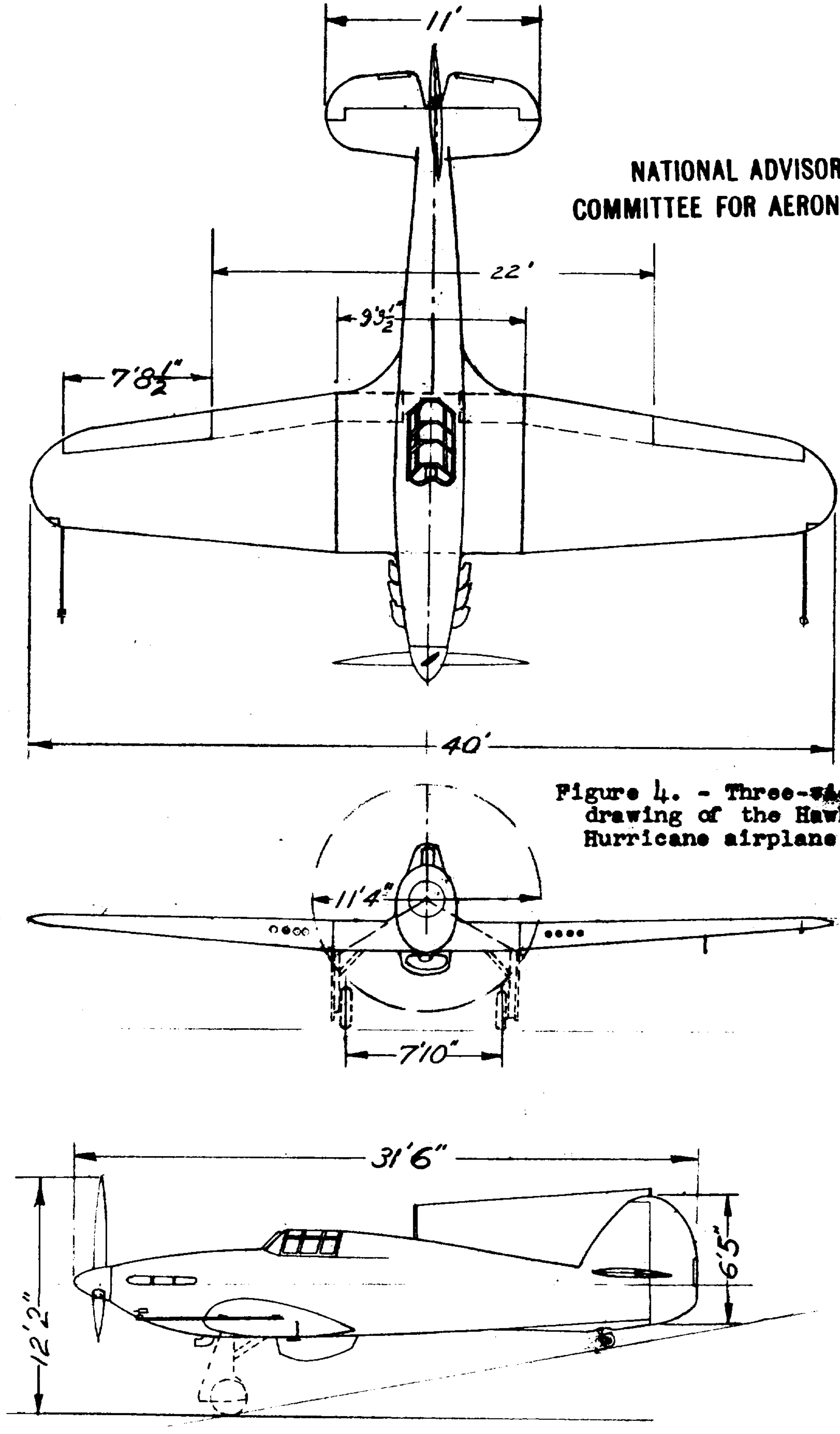

Figure 4. - Three-view drawing of the Hawker Hurricane airplane.

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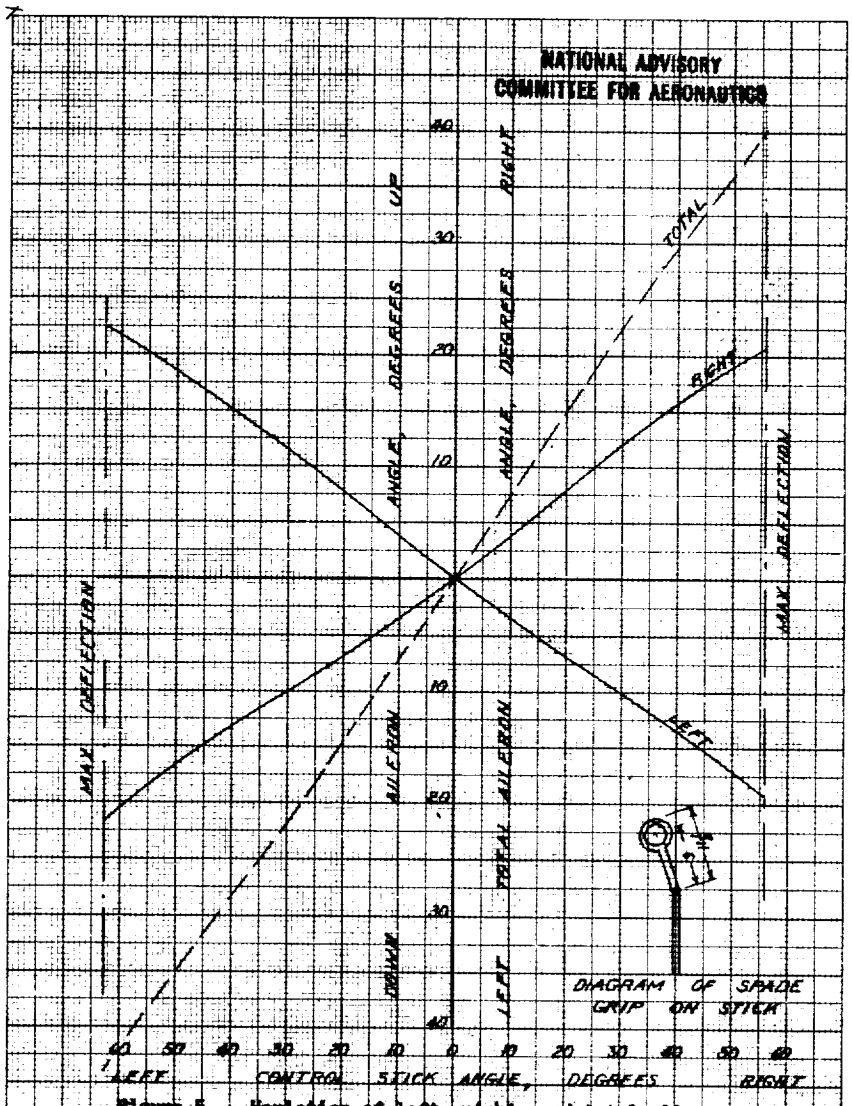

Figure 5. - Variation of left, right, and total aileron angles with control-stick angle. Hawker Hurricane airplane.

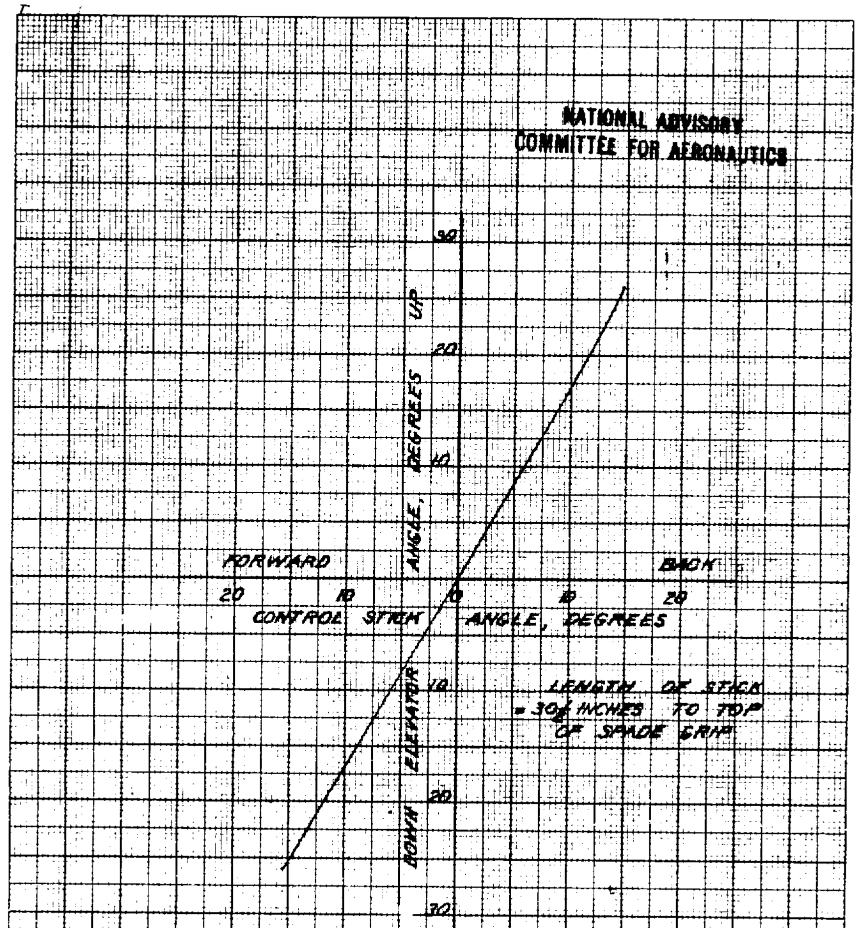

Figure 6. - Variation of elevator angle as measured from the thrust axis with control-stick angle. Hawker Hurricane airplane.

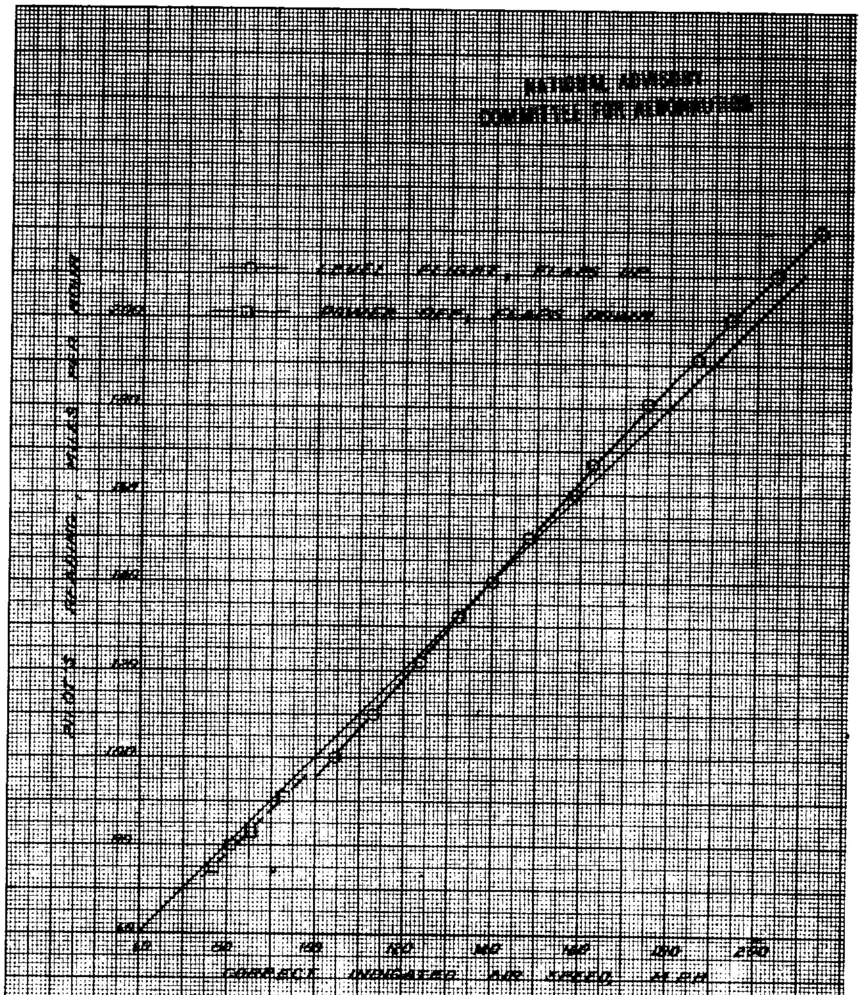

Figure 7. - Calibration of pilot's airspeed meter in Hawker Hurricane airplane.

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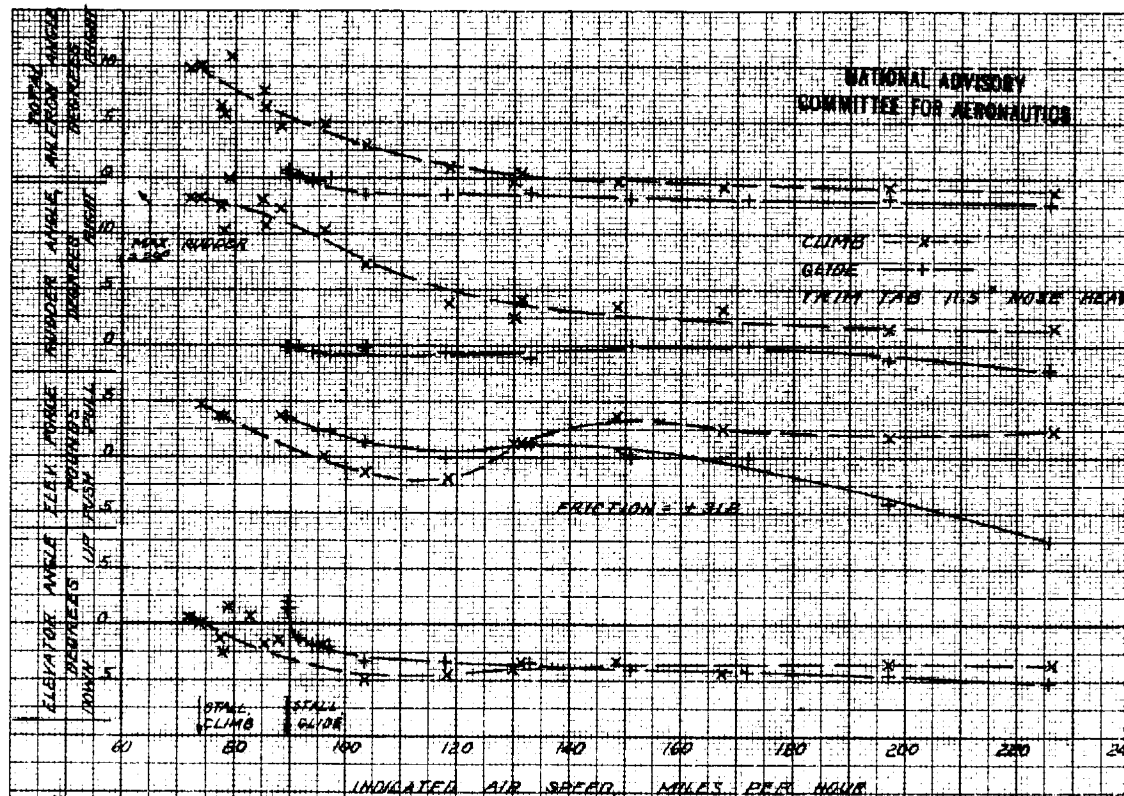

Figure 8. - Variation of elevator angle, elevator force, rudder angle, and aileron angle required for trim with indicated airspeed in the climbing and gliding conditions. Hawker Hurricane airplane.

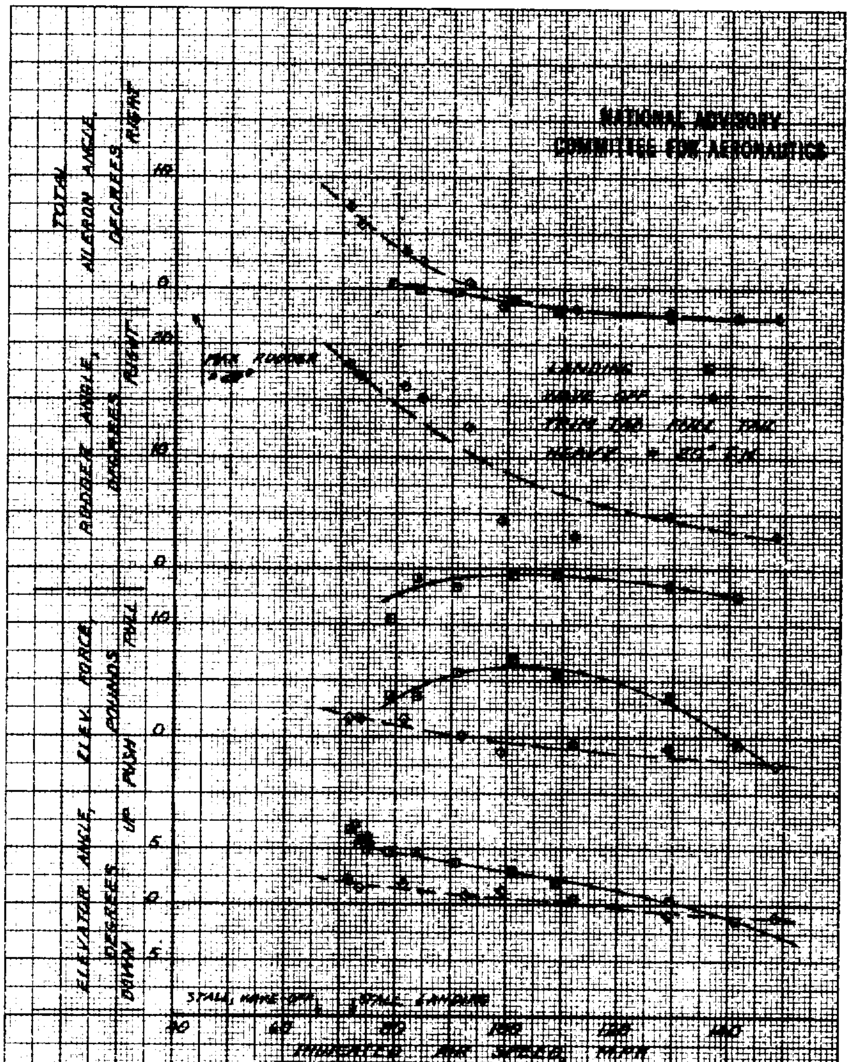

Figure 9. - Variation of elevator angle, elevator force, rudder angle, and aileron angle required for trim with indicated airspeed in the landing and wave-off conditions. Hawker Hurricane airplane.

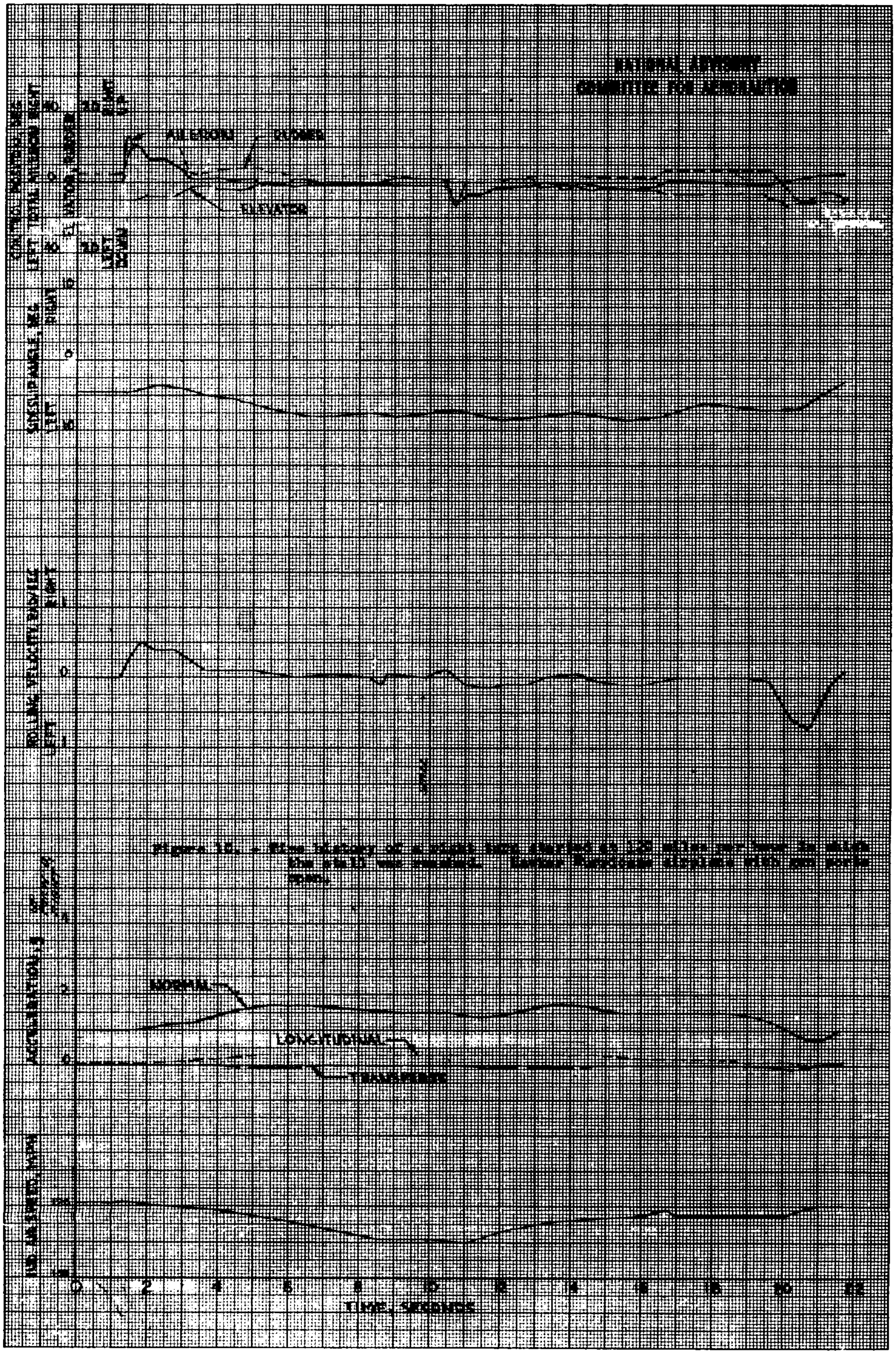

Figure 10. - Time history of a right turn started at 120 miles per hour in which the stall was reached. Hawker Hurricane airplane with gun ports open.

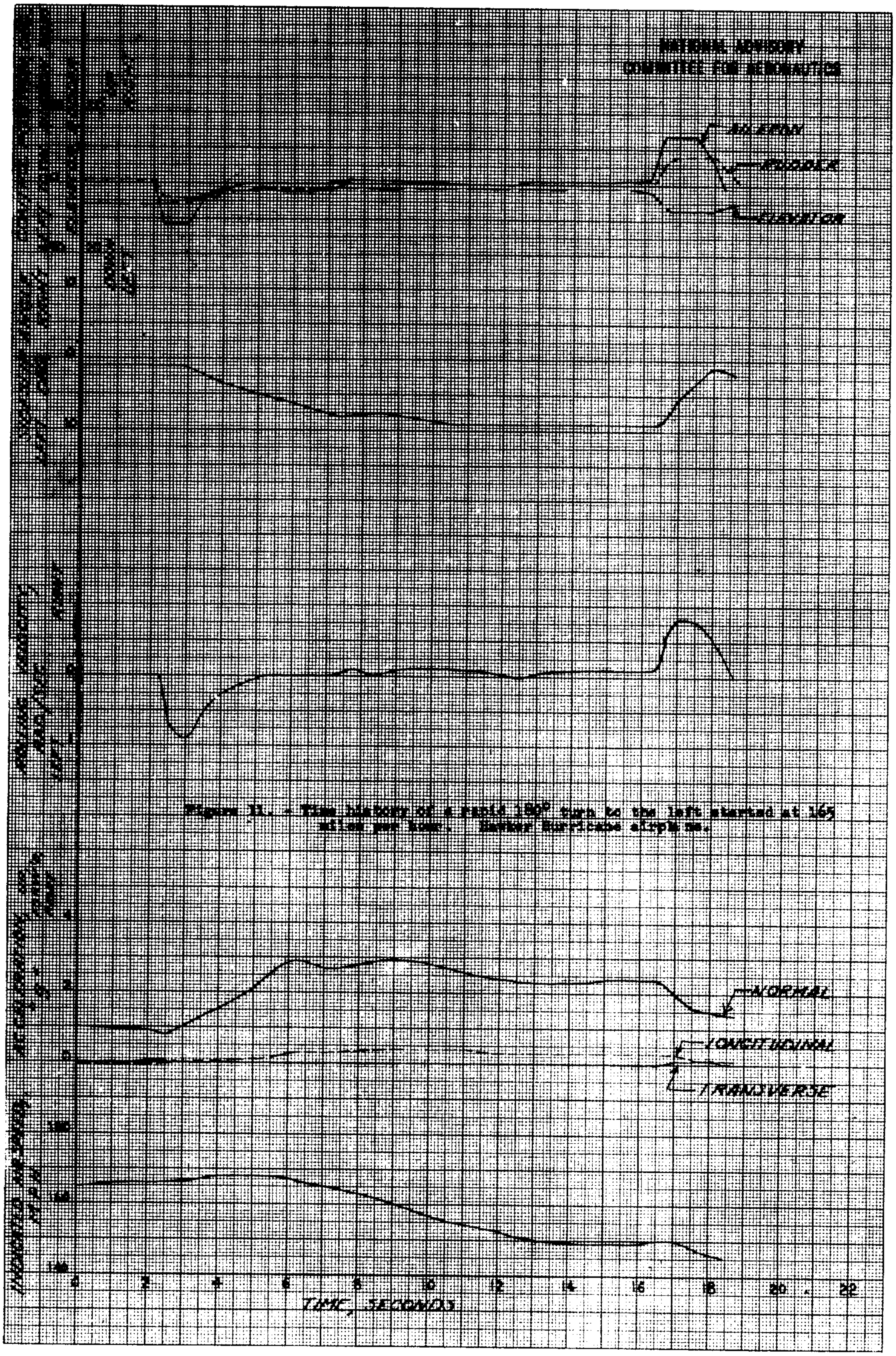

Figure 11. - Time history of a rapid 180° turn to the left started at 165 miles per hour. Hawker Hurricane airplane.

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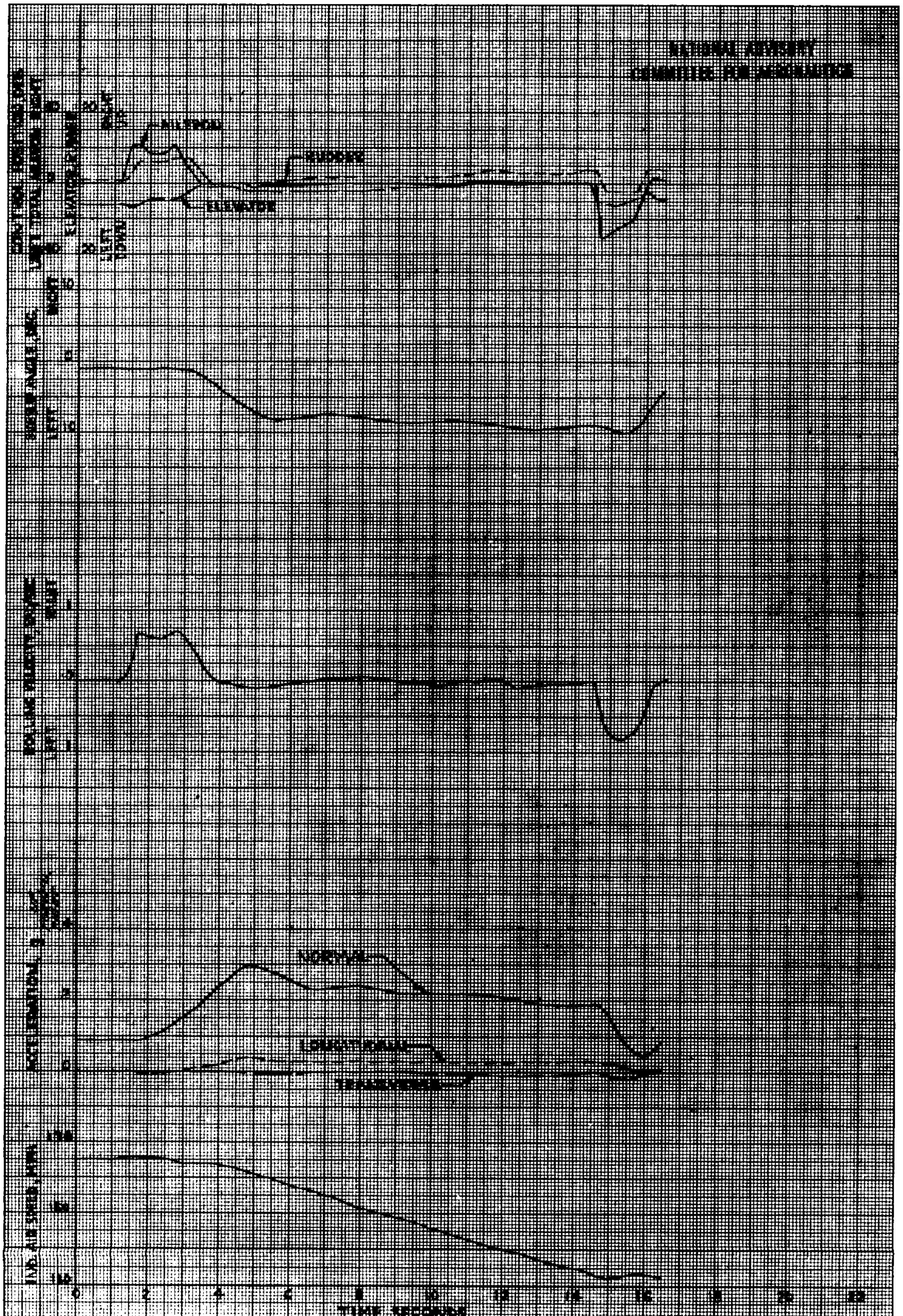

Figure 12. - Time history of a rapid 180° turn to the right started at 165 miles per hour. Hawker Hurricane airplane.

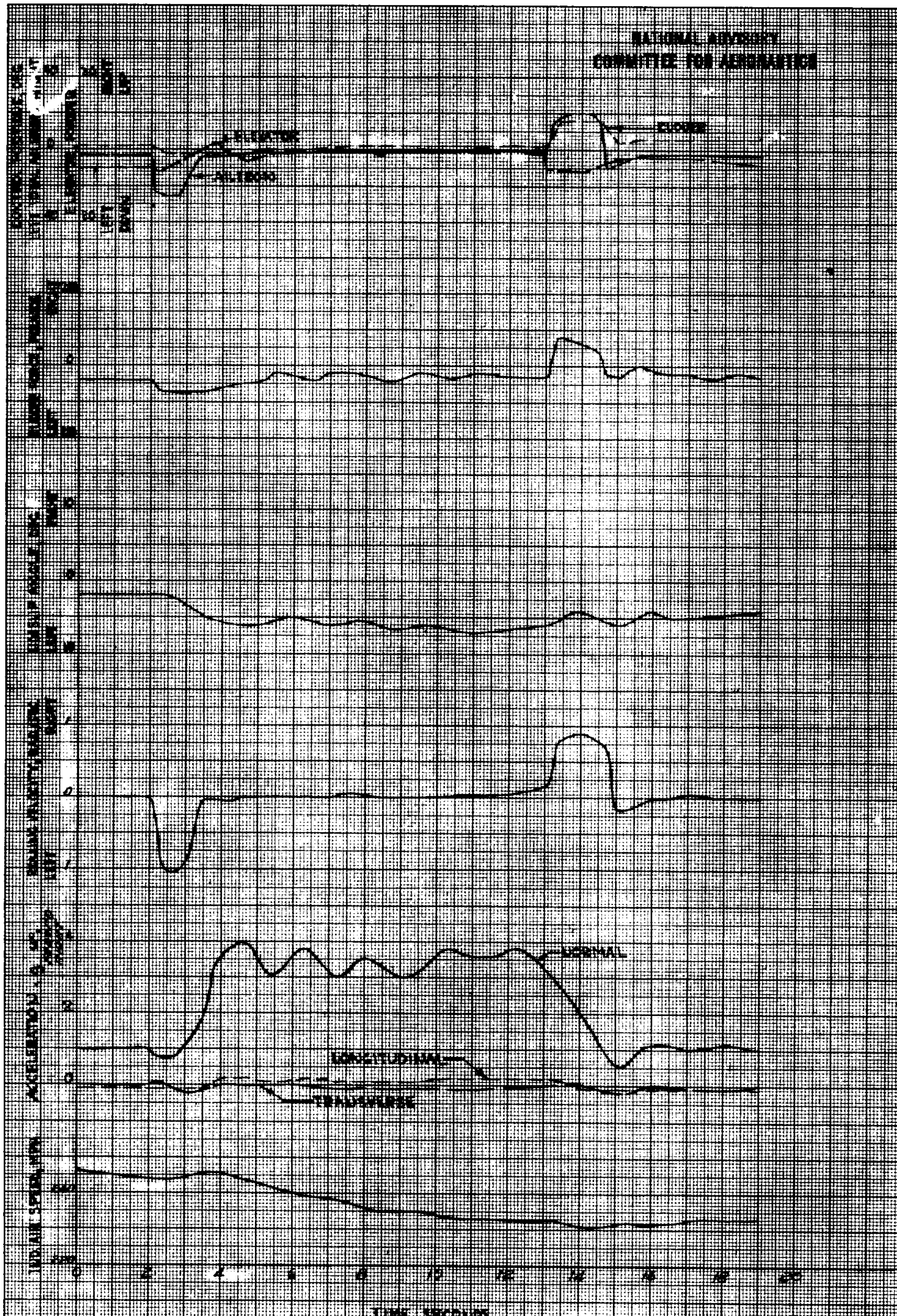

Figure 15. - Time history of a rapid 180° turn to the left started at 245 miles per hour, Hawker Hurricane airplane.

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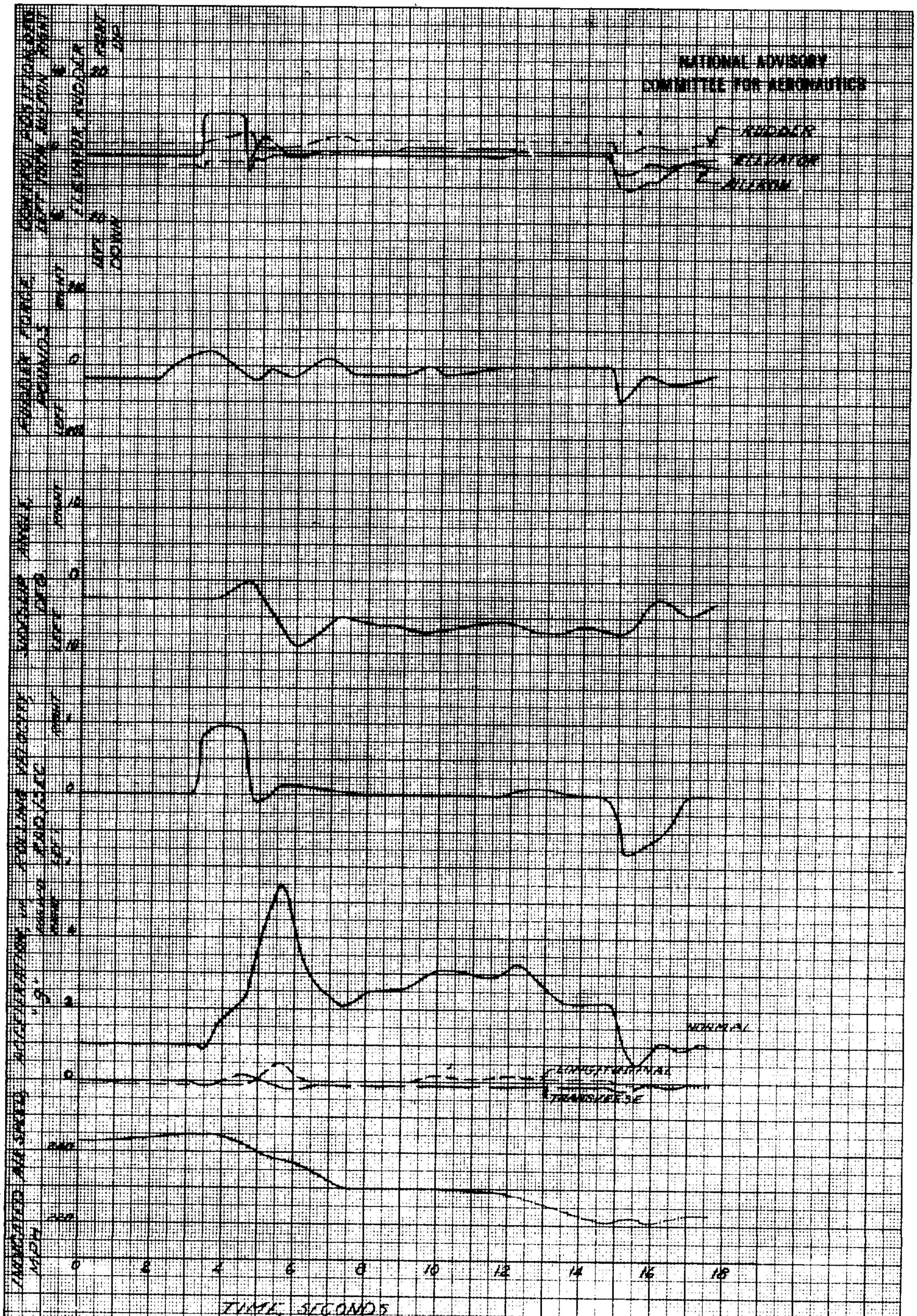

Figure 14. - Time history of a rapid 180° turn to the right started at 243 miles per hour. Hawker Hurricane airplane.

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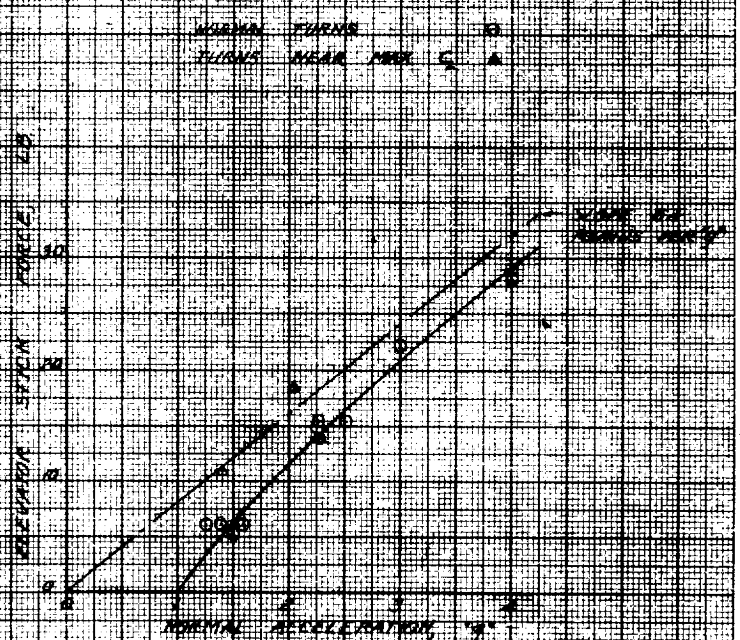

Figure 15. - Variation of stick force with normal acceleration in 180° turns. Hawker Hurricane airplane.

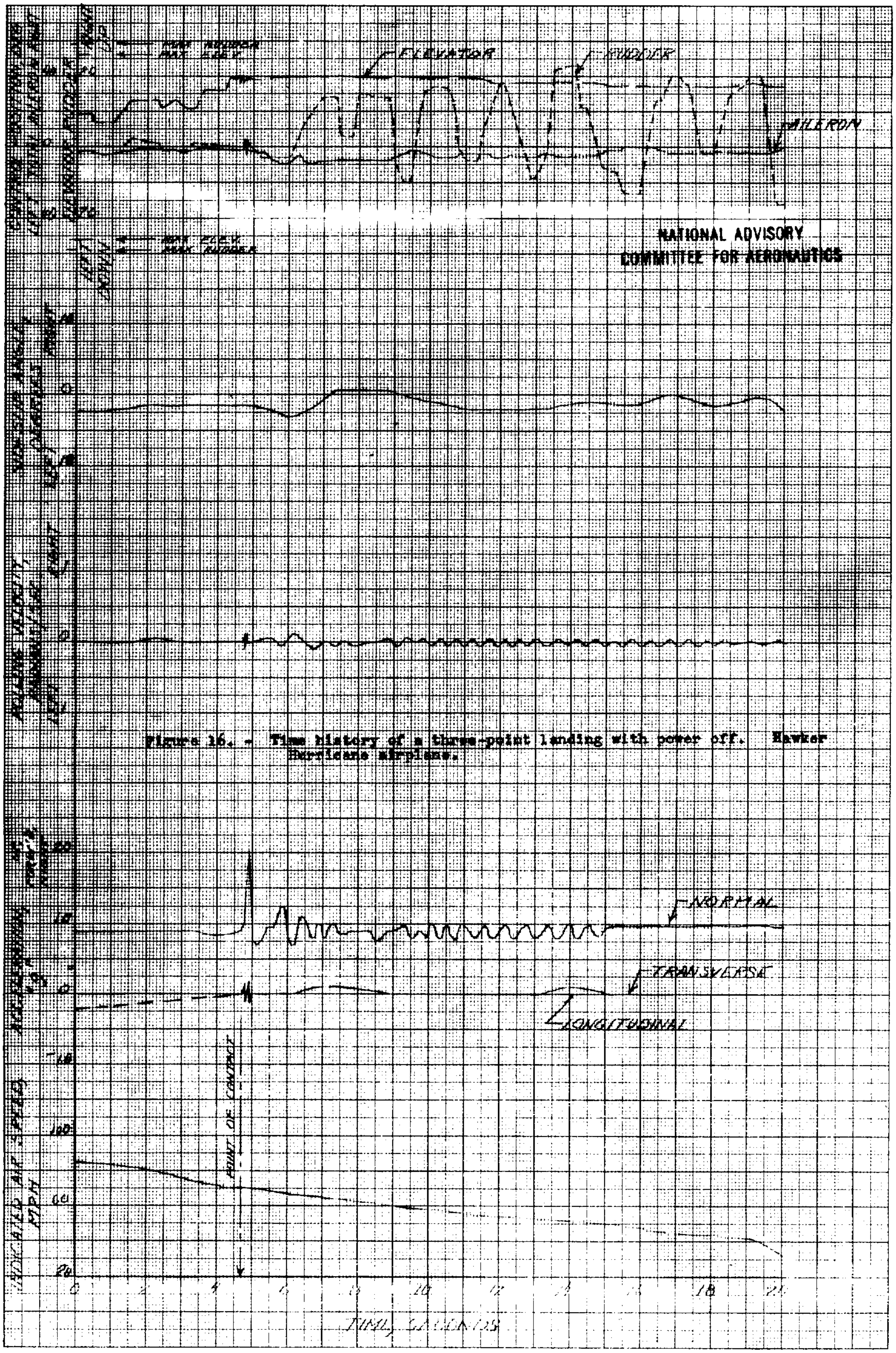

Figure 16. - Time history of a three-point landing with power off. Hawker Hurricane airplane.

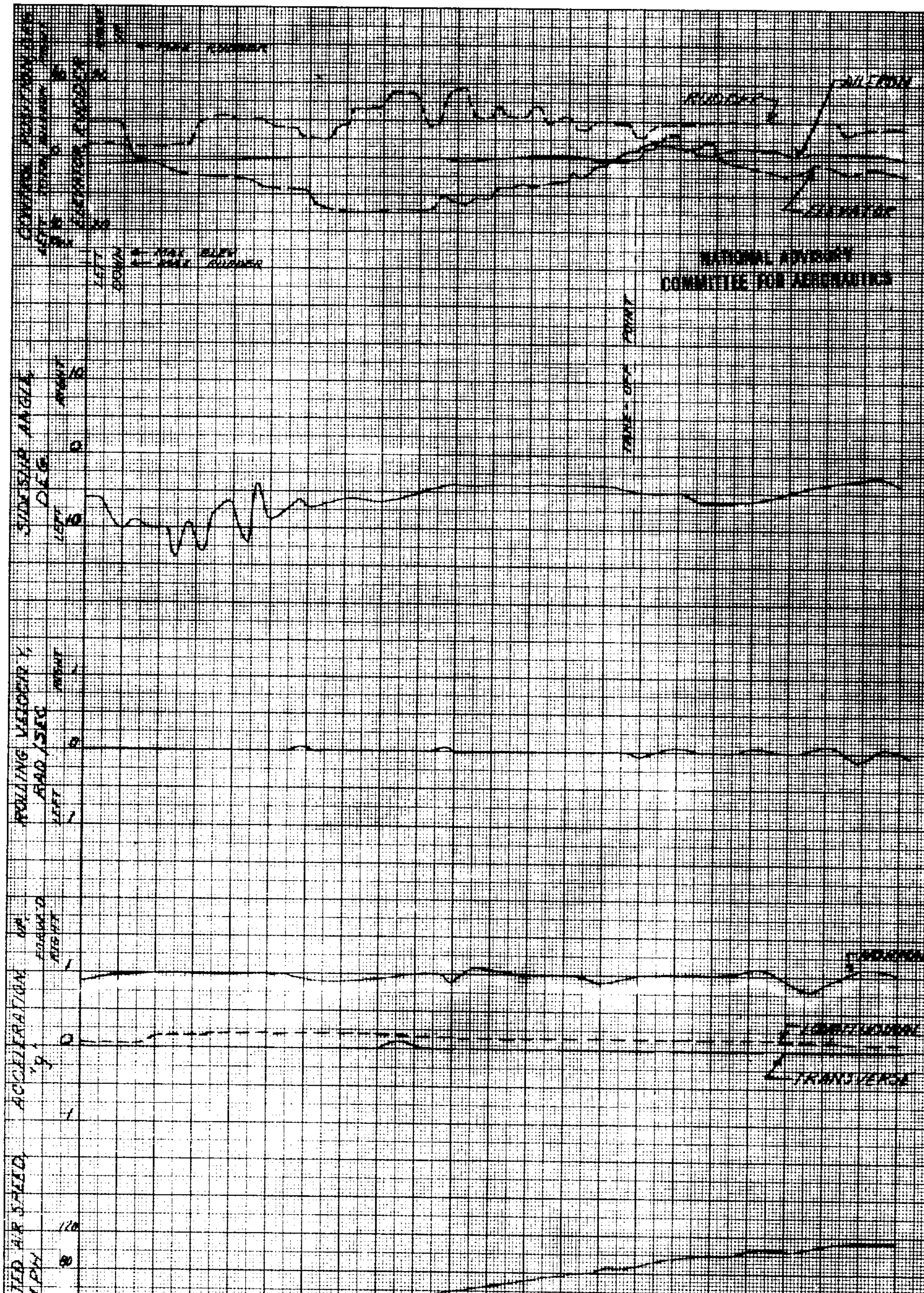

Figure 17. - Time history of a tail high take-off. Hawker Hurricane airplane.

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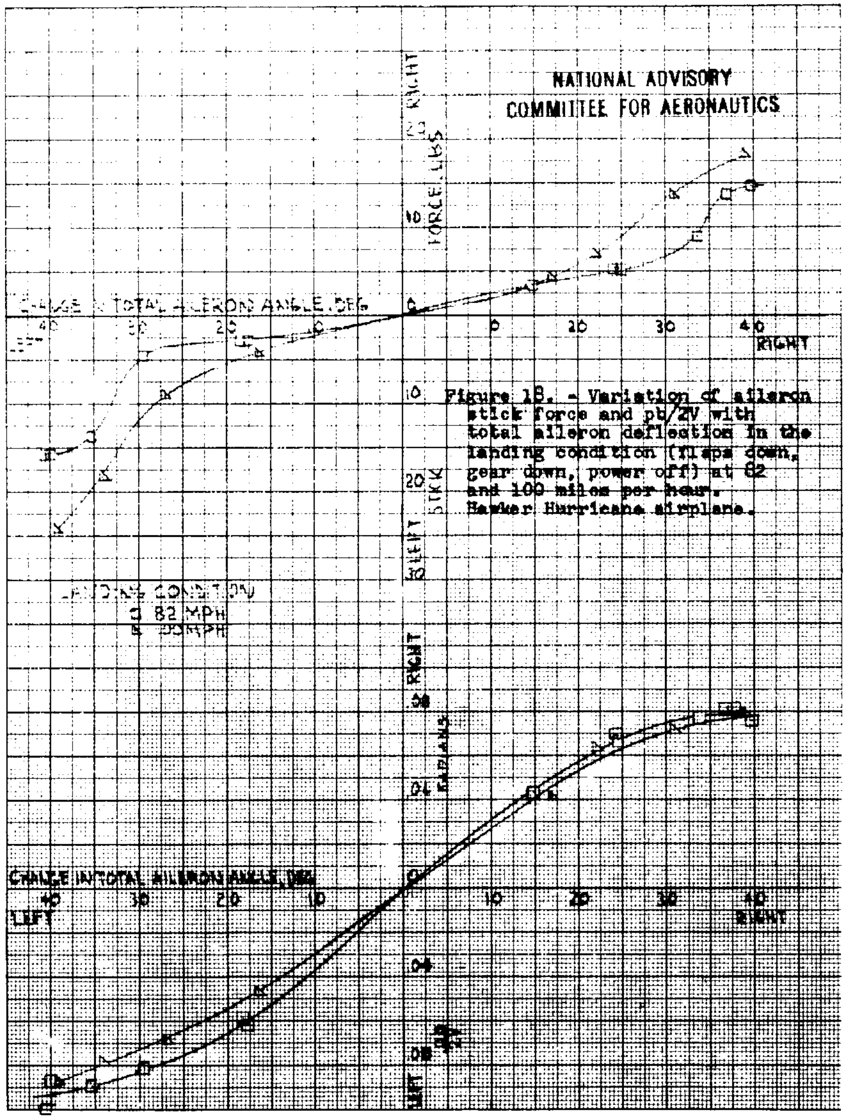

Figure 18. - Variation of aileron stick force and pb/2V with total aileron deflection in the landing condition (flaps down, gear down, power off) at 82 and 100 miles per hour. Hawker Hurricane airplane.

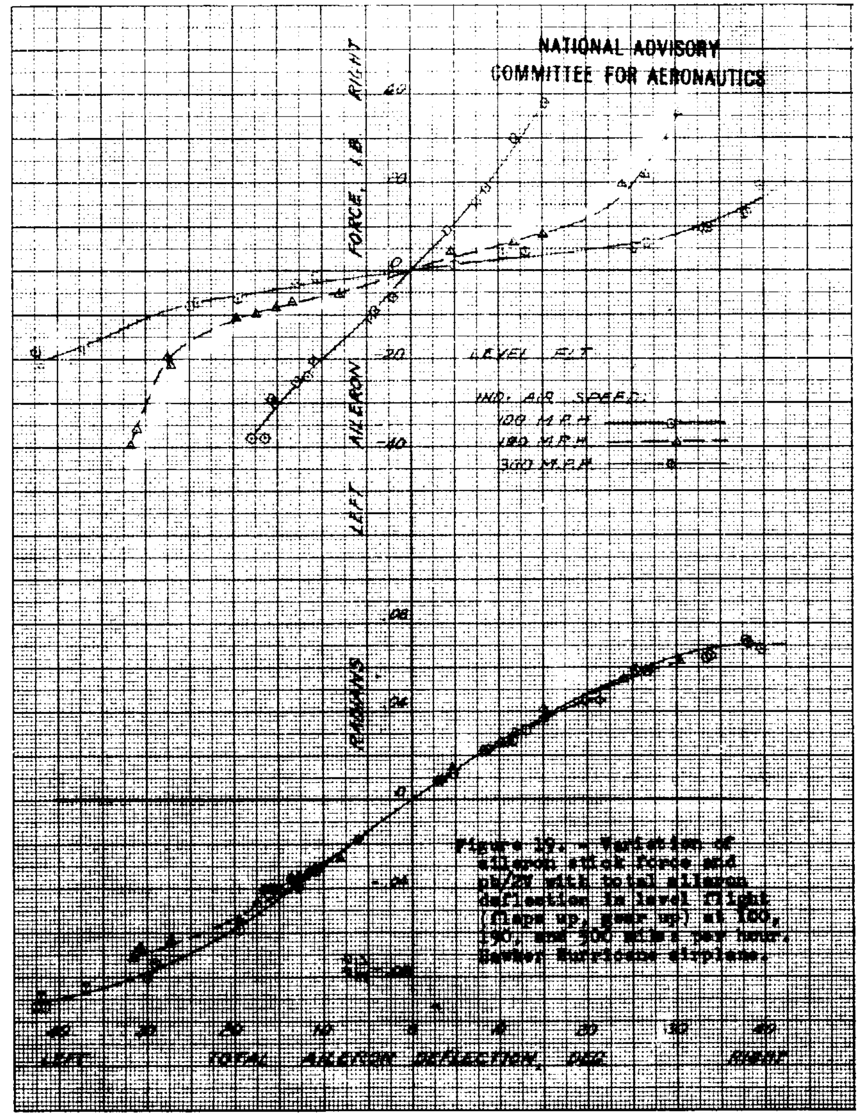

Figure 19. - Variation of aileron stick force and pb/2V with total aileron deflection in level flight (flaps up, gear up) at 100, 190, and 300 miles per hour. Hawker Hurricane airplane.

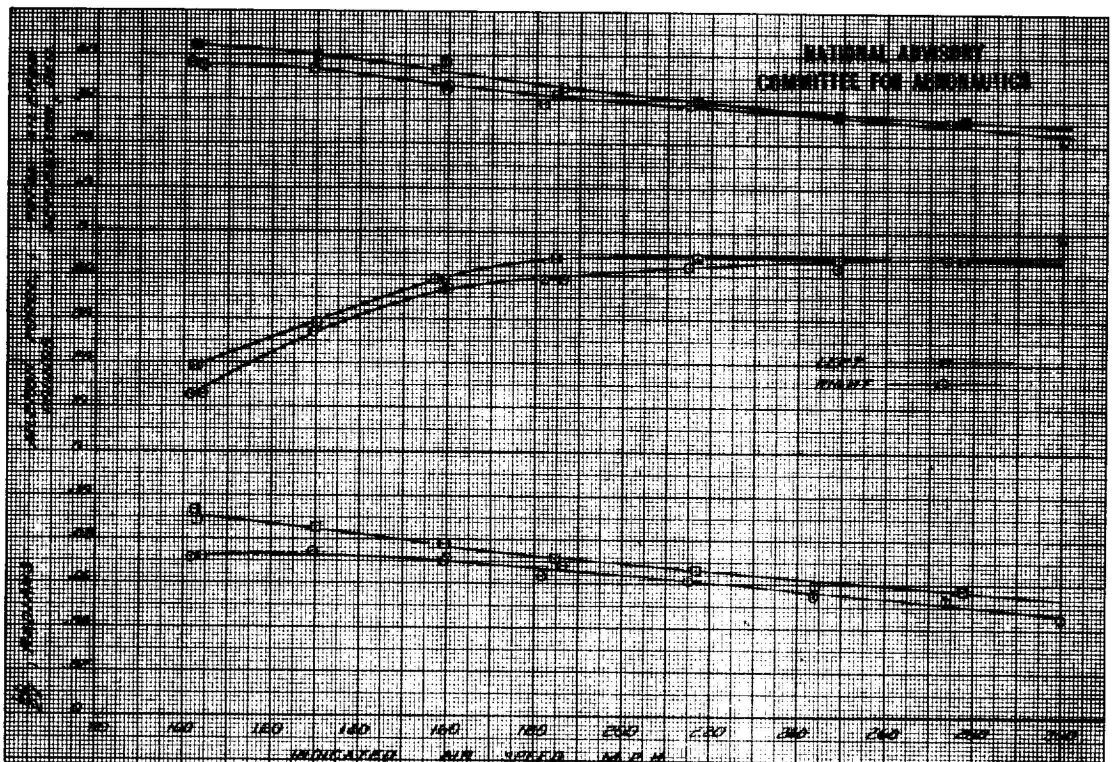

Figure 20. - Variation of maximum obtainable total aileron deflection, aileron force, and pb/2V with indicated airspeed in aileron rolls in level flight (flaps up, gear up). Hawker Hurricane airplane.

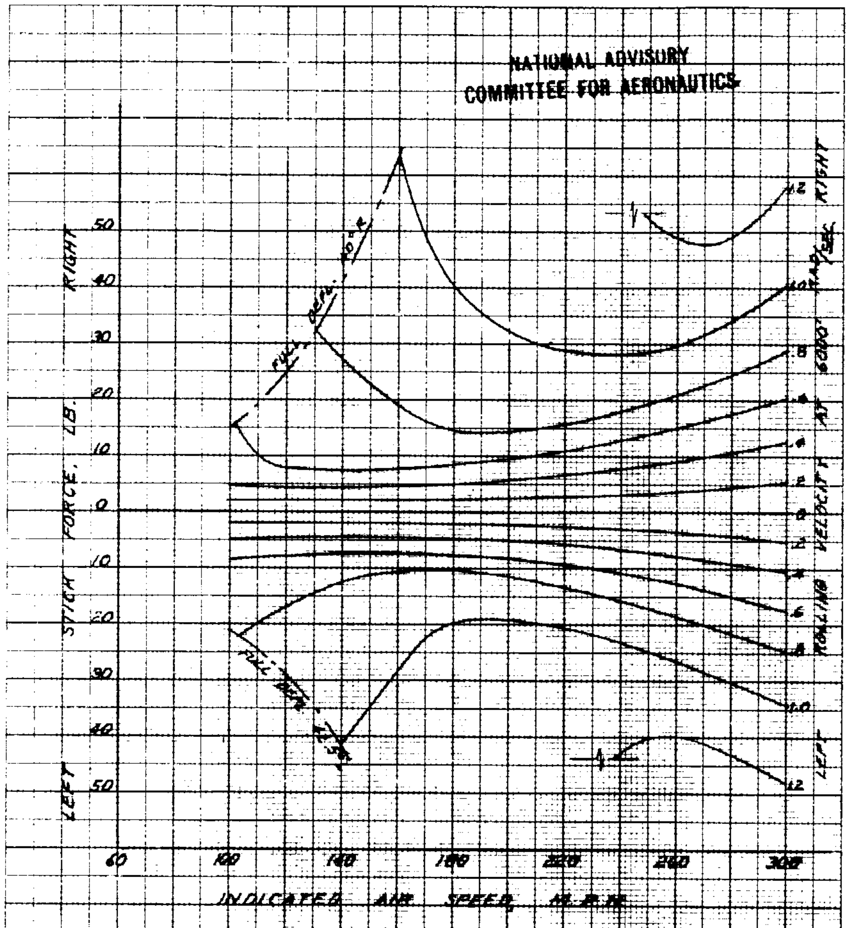

Figure 21. - Variation of stick force with indicated airspeed for various rolling velocities in level flight. Hawker Hurricane airplane.

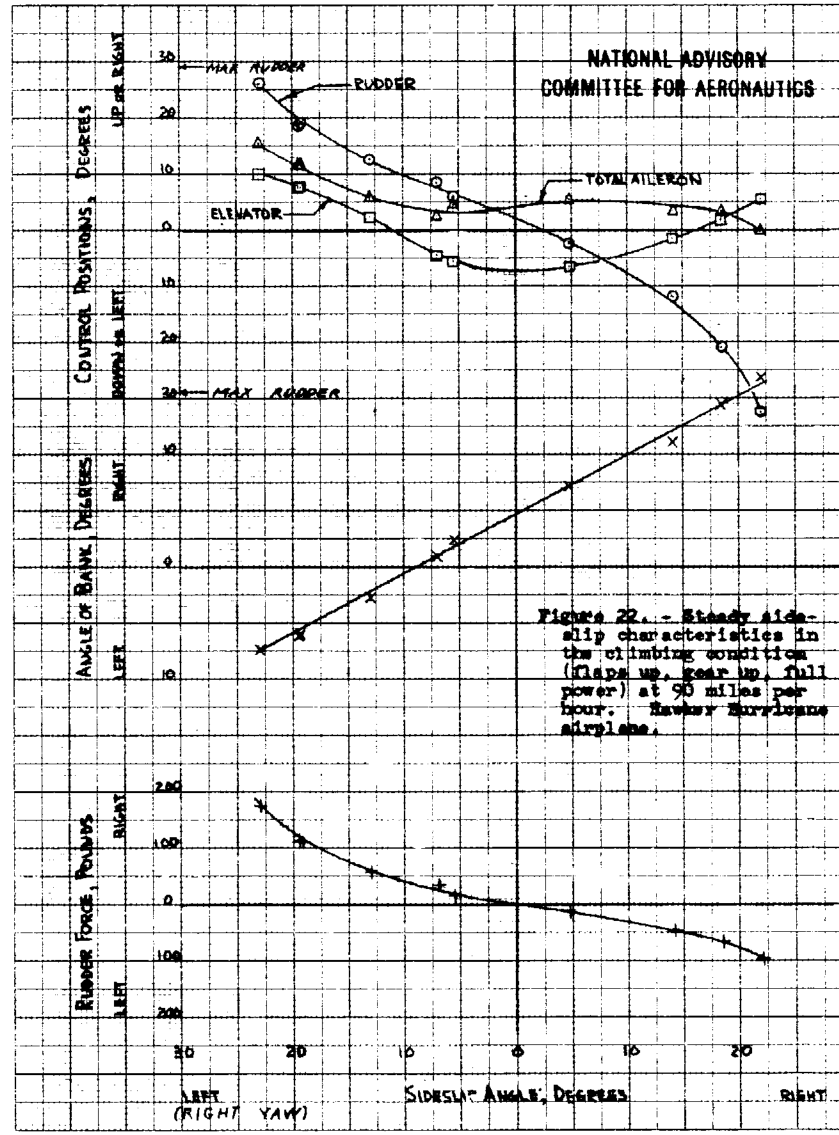

Figure 22. - Steady side-slip characteristics in the climbing condition (flaps up, gear up, full power) at 90 miles per hour. Hawker Hurricane airplane.

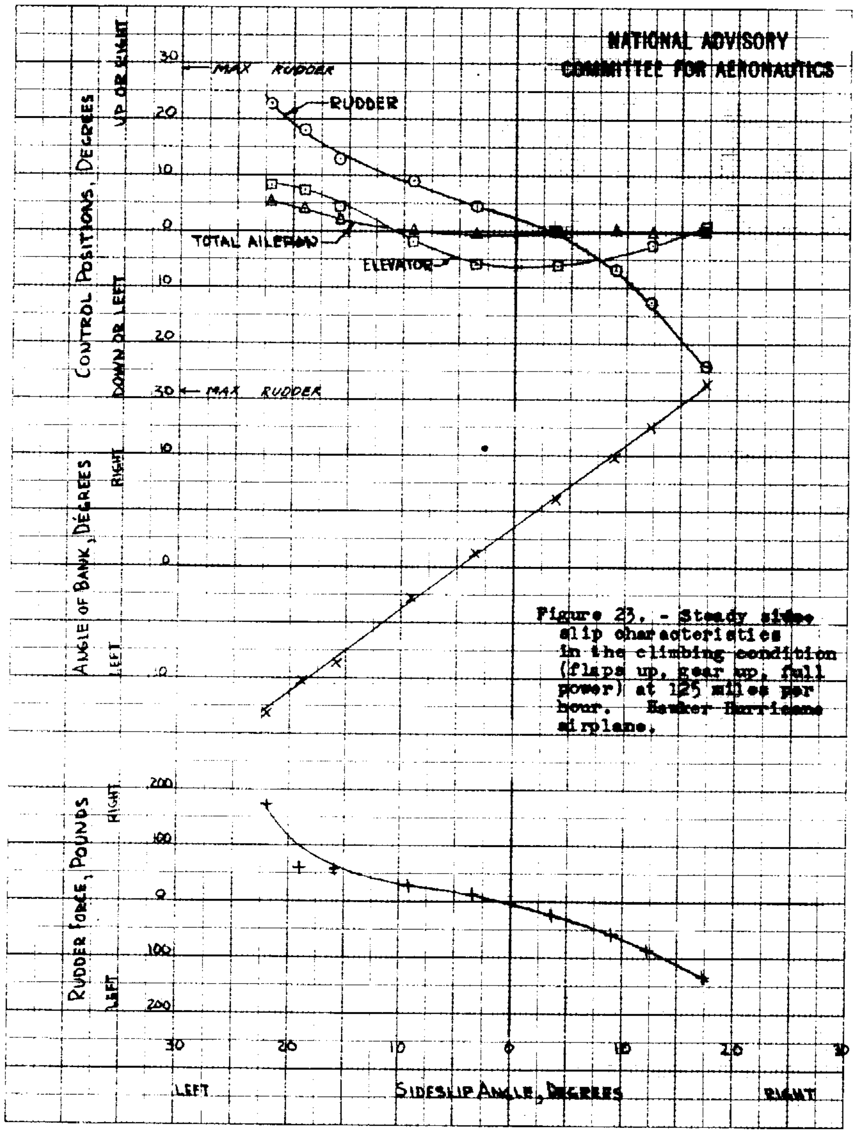

Figure 23. - Steady sideslip characteristics in the climbing condition (flaps up, gear up, full power) at 125 miles per hour. Hawker Hurricane airplane.

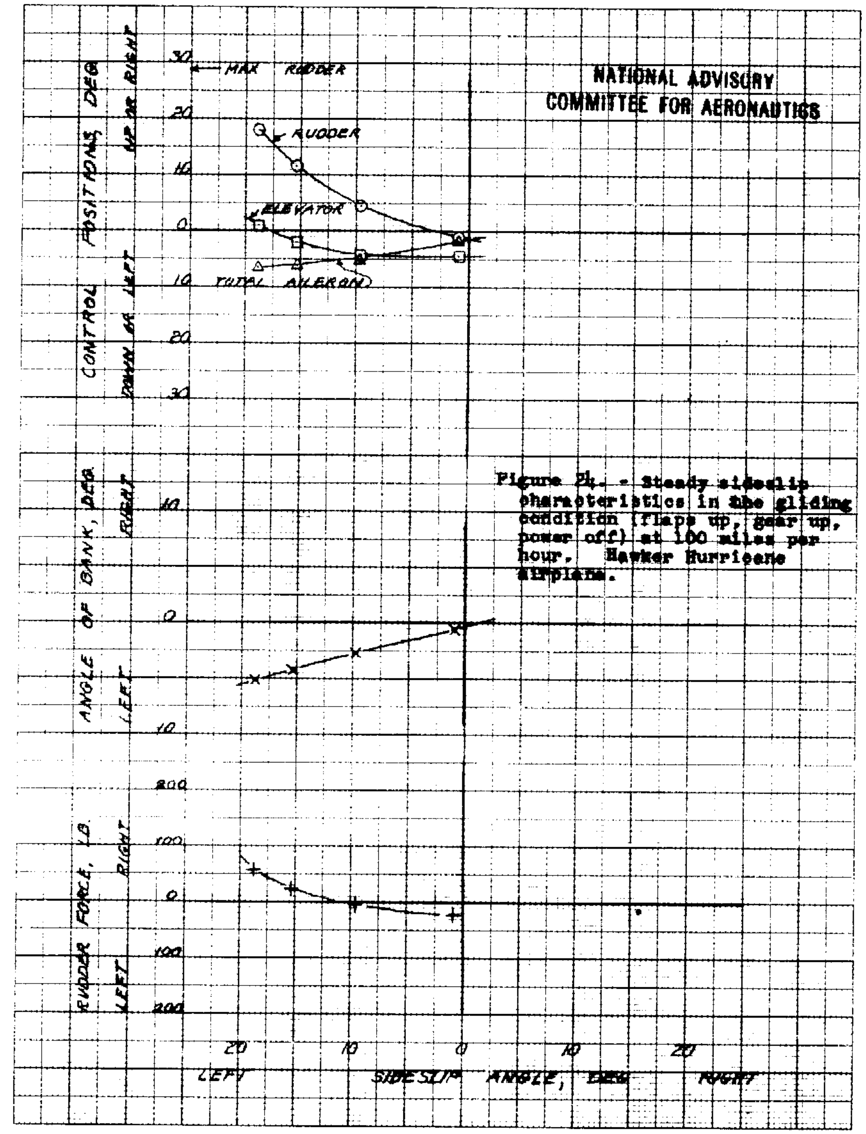

Figure 24. - Steady sideslip characteristics in the gliding condition (flaps up, gear up, power off) at 100 miles per hour. Hawker Hurricane airplane.

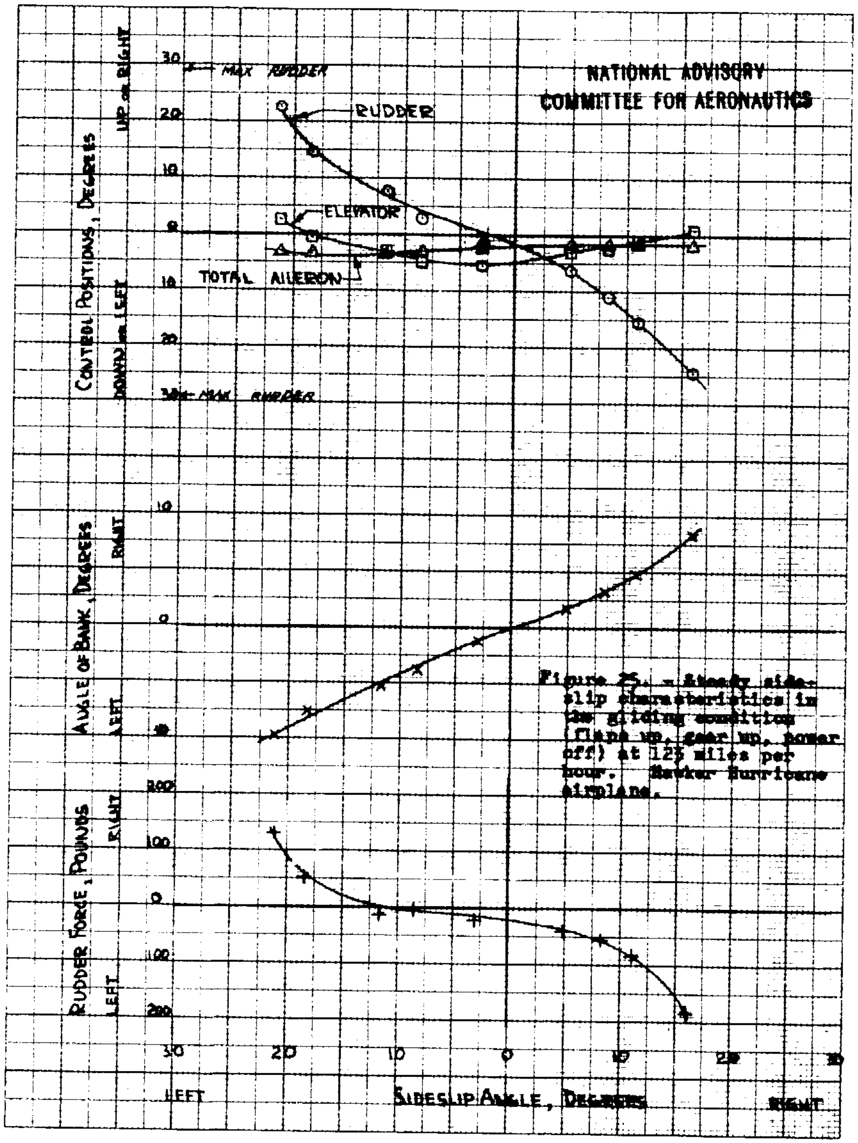

Figure 25. - Steady side-slip characteristics in the gliding condition (flaps up, gear up, power off) at 123 miles per hour. Hawker Hurricane airplane.

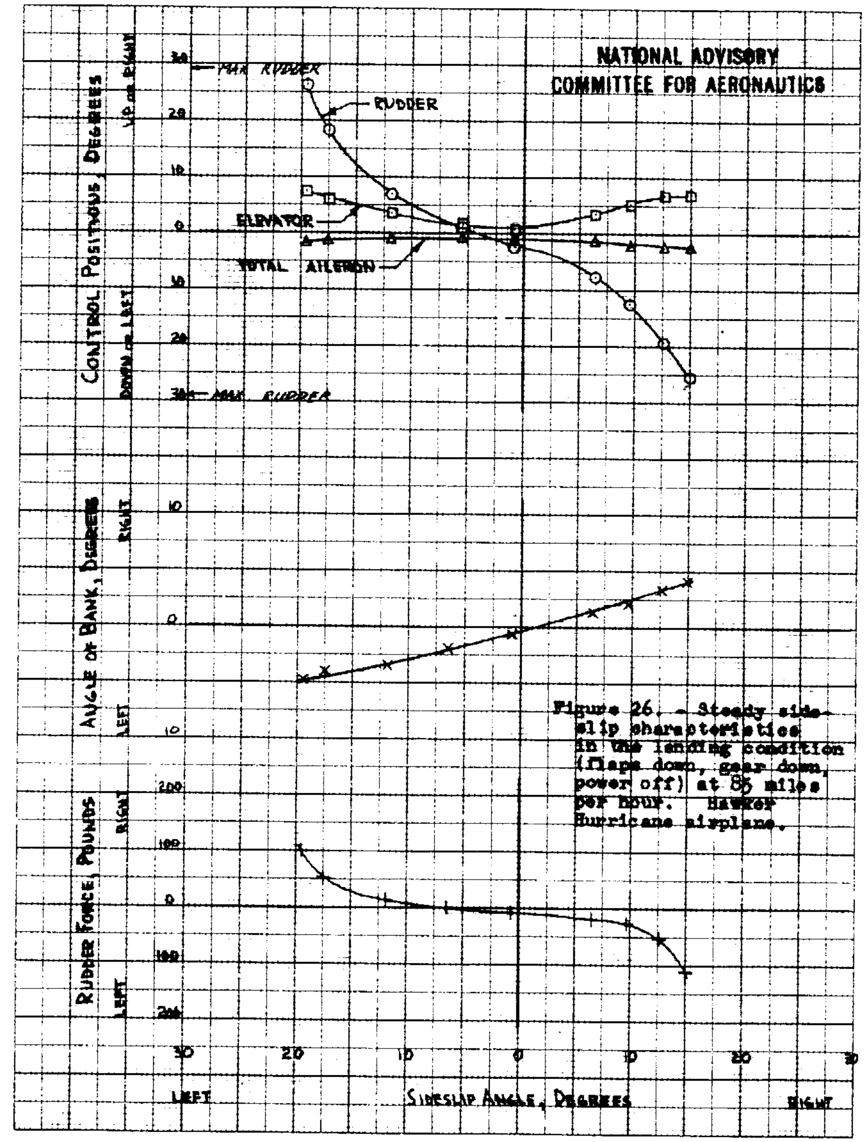

Figure 26. - Steady side-slip characteristics in the landing condition (flaps down, gear down, power off) at 85 miles per hour. Hawker Hurricane airplane.

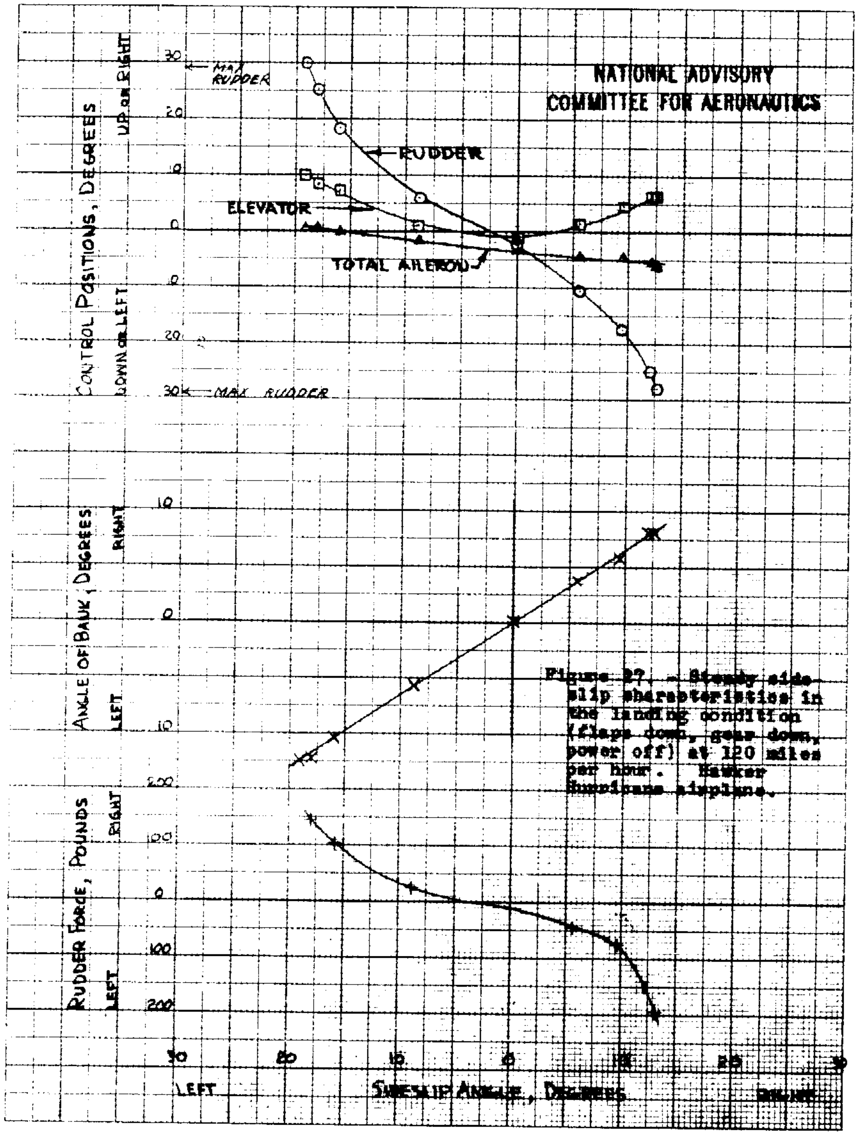

Figure 27. - Steady side-slip characteristics in the landing condition (flaps down, gear down, power off) at 120 miles per hour. Hawker Hurricane airplane.

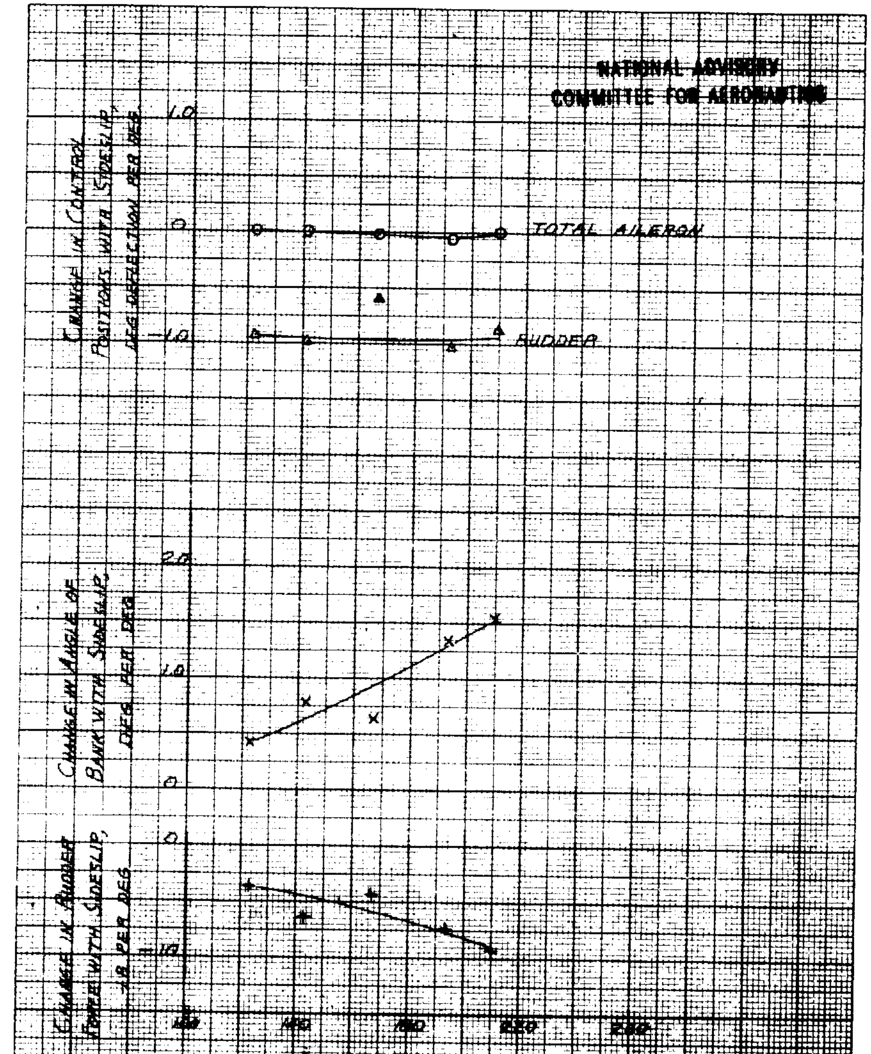

Figure 28. - Steady sideslip characteristics for small rudder deflections in level flight condition (flaps up, gear up). Hawker Hurricane airplane.

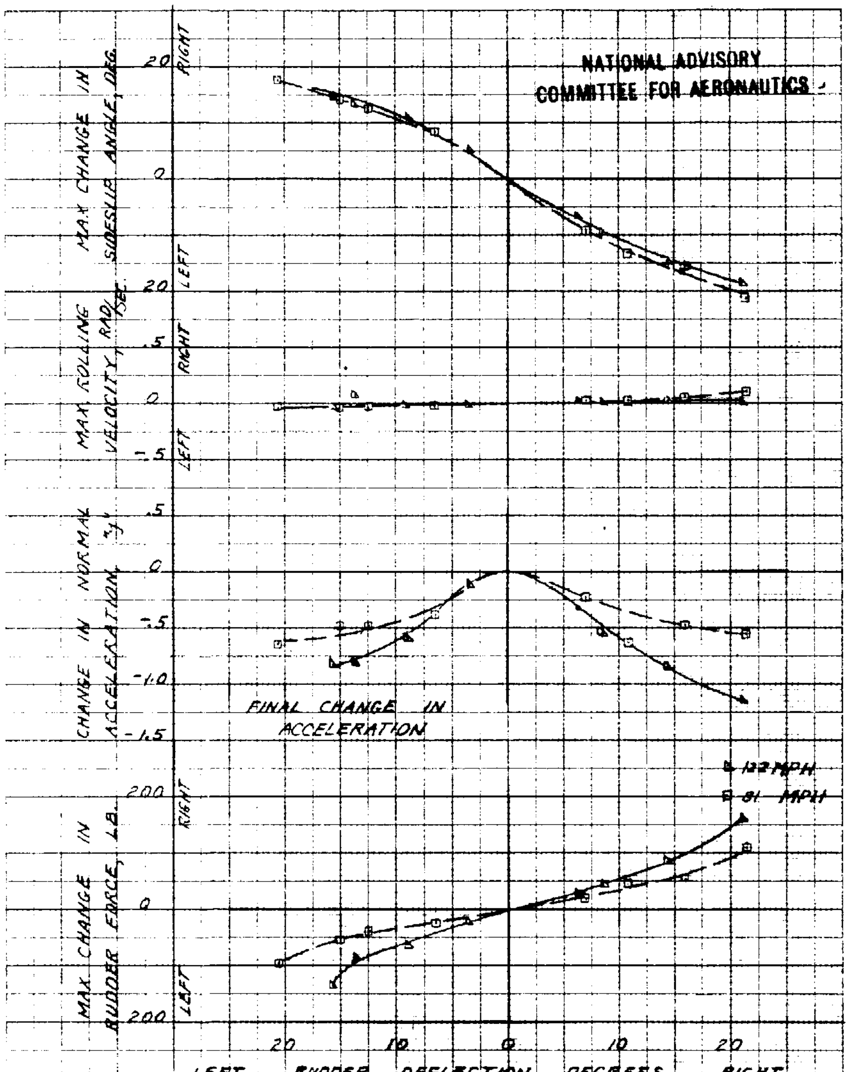

Figure 29. - Variation of maximum sideslip angle, rolling velocity, final change in normal acceleration, and change in rudder force with rudder deflection in abrupt rudder kicks in the landing condition. Hawker Hurricane airplane.

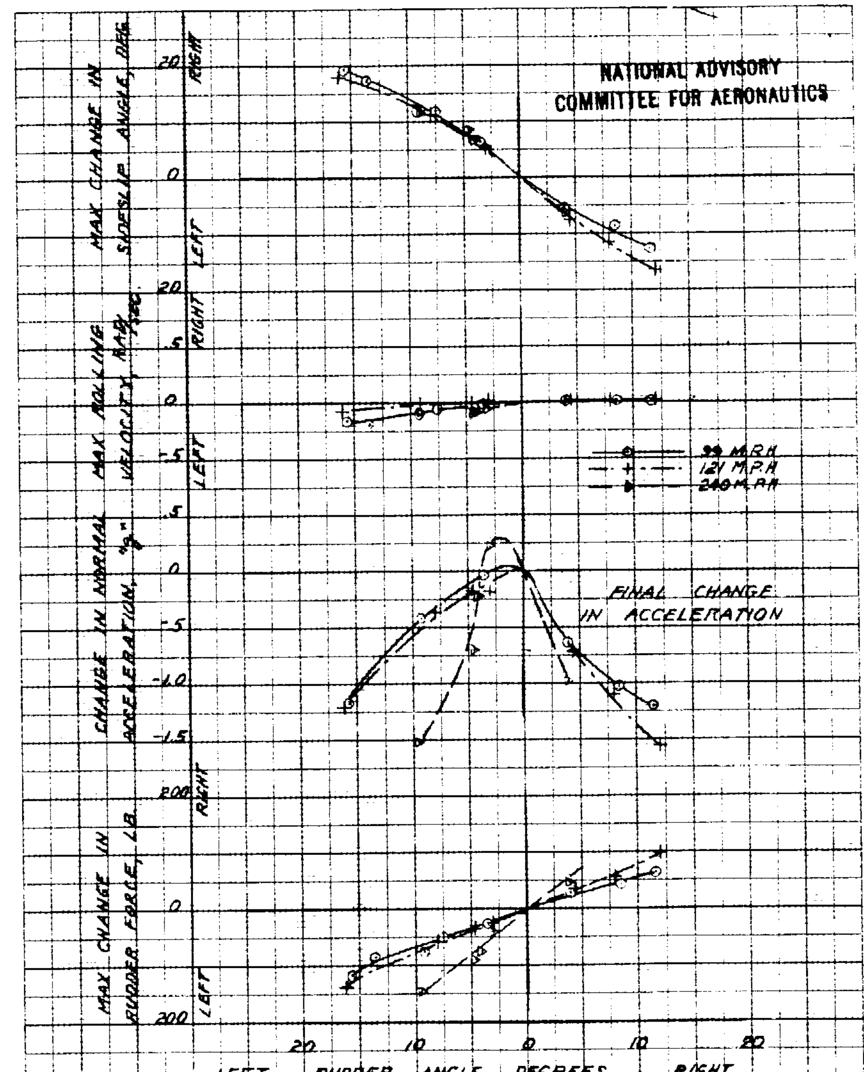

Figure 30. - Variation of maximum sideslip angle, rolling velocity, final change in normal acceleration, and change in rudder force with rudder deflection in abrupt rudder kicks in level flight (flaps up, gear up). Hawker Hurricane airplane.

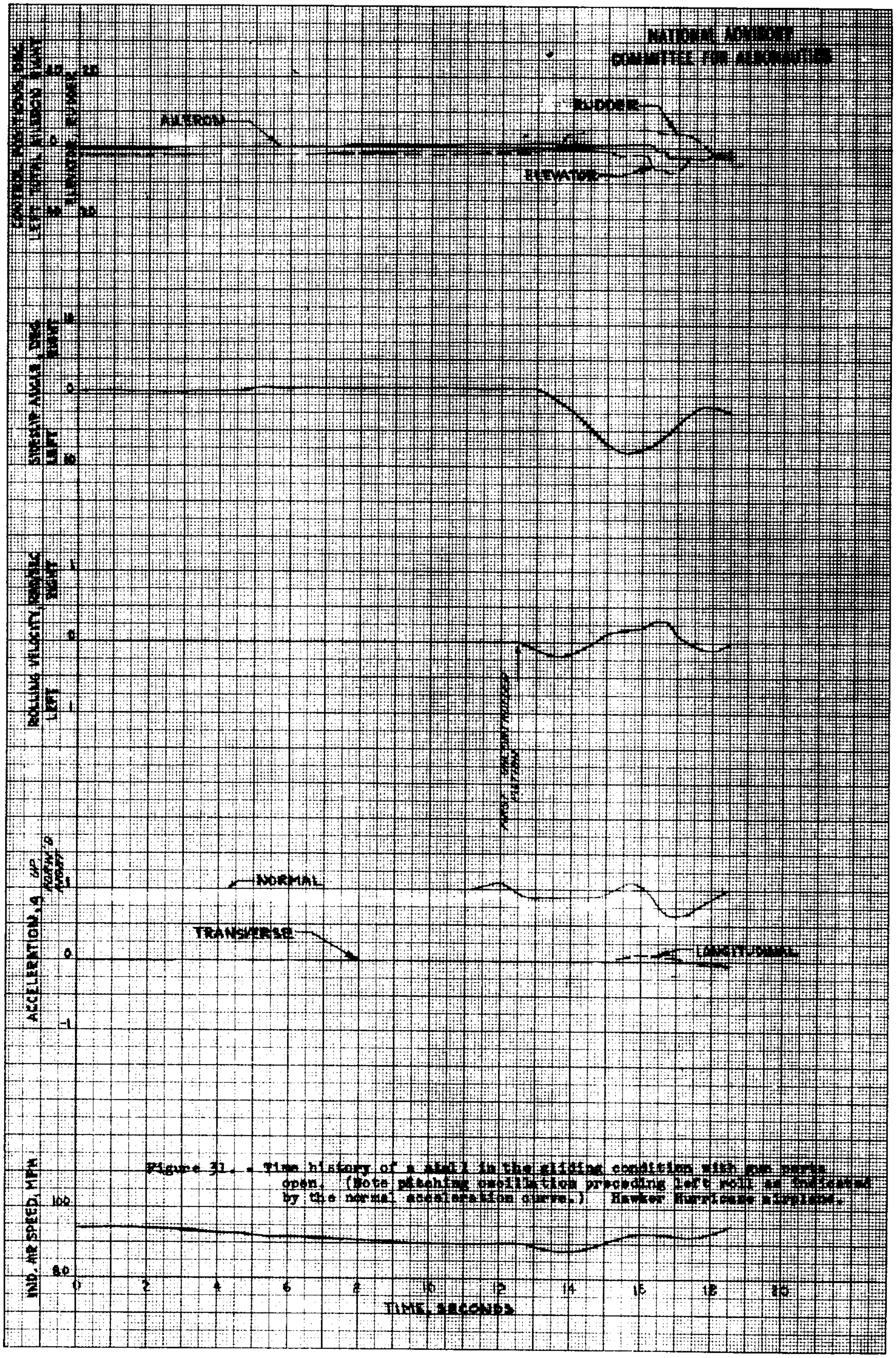

Figure 31. - Time history of a stall in the gliding condition with gun ports open. (Note pitching oscillation preceding left roll as indicated by the normal acceleration curve.) Hawker Hurricane airplane.

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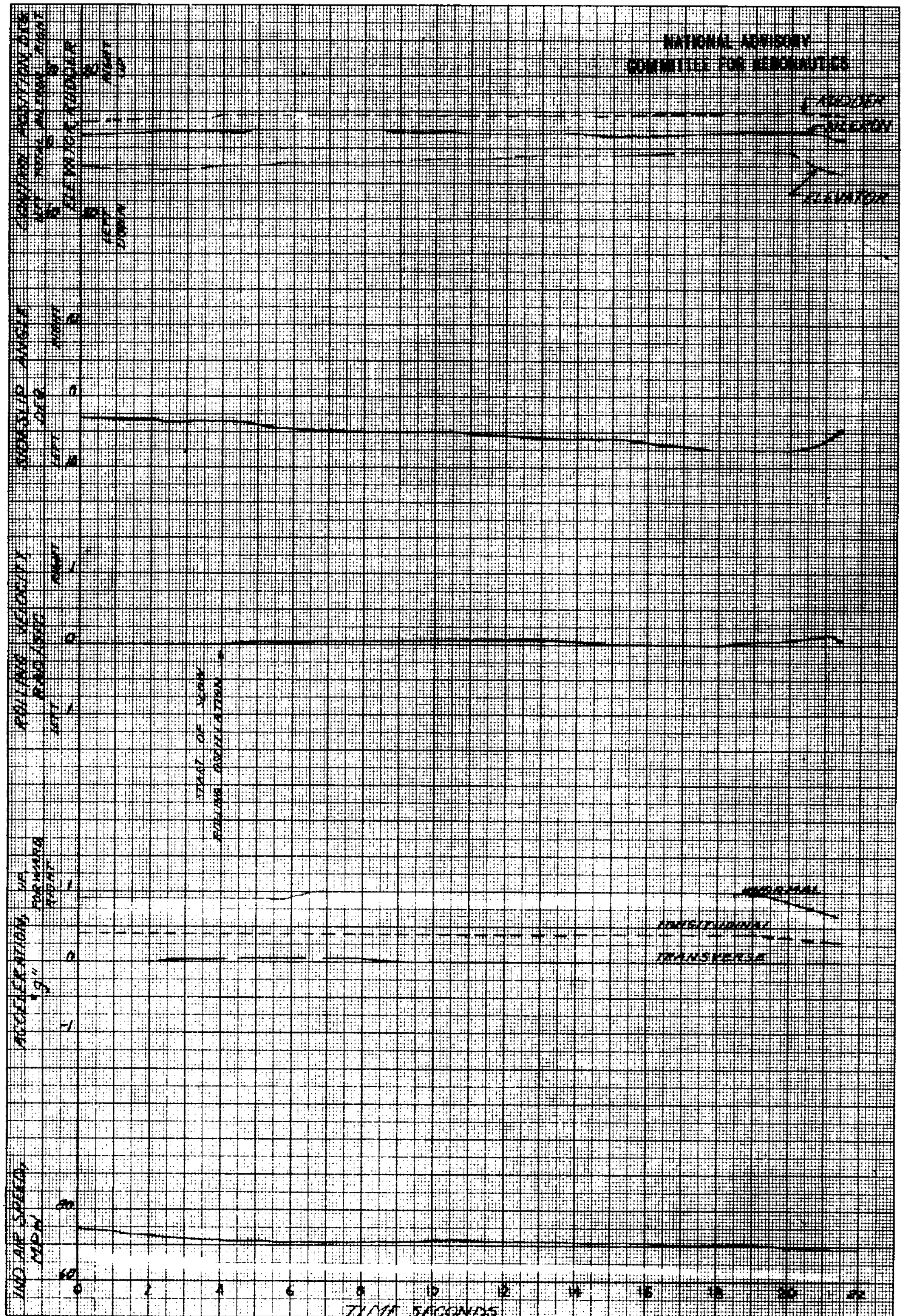

Figure 32. - Time history of a stall in the climbing condition with gun ports closed. (Note slowly increasing rolling oscillation.) Hawker Hurricane airplane.

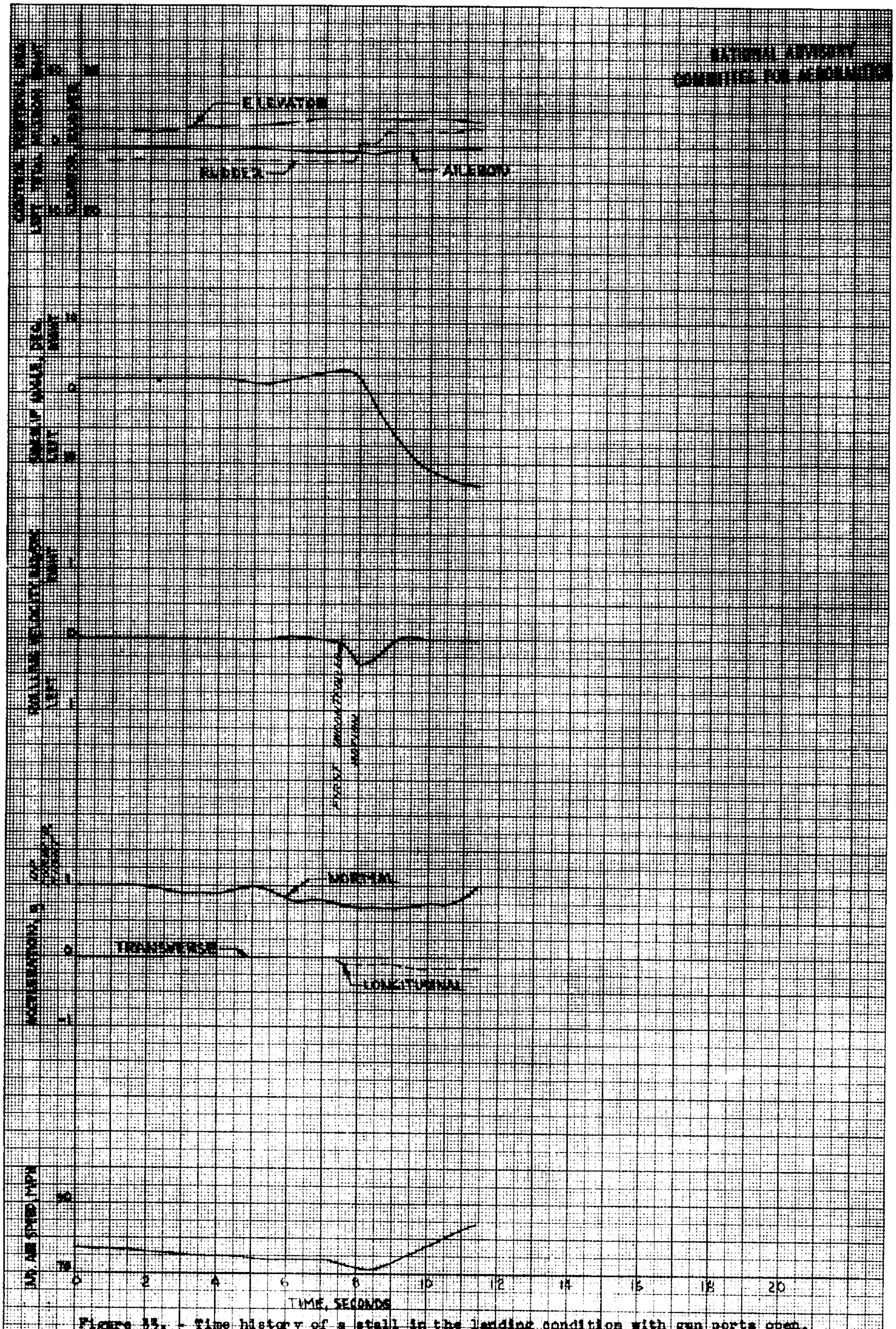

Figure 35. - Time history of a stall in the landing condition with gun ports open. (Down pitching motion preceded left roll.) Hawker Hurricane airplane.

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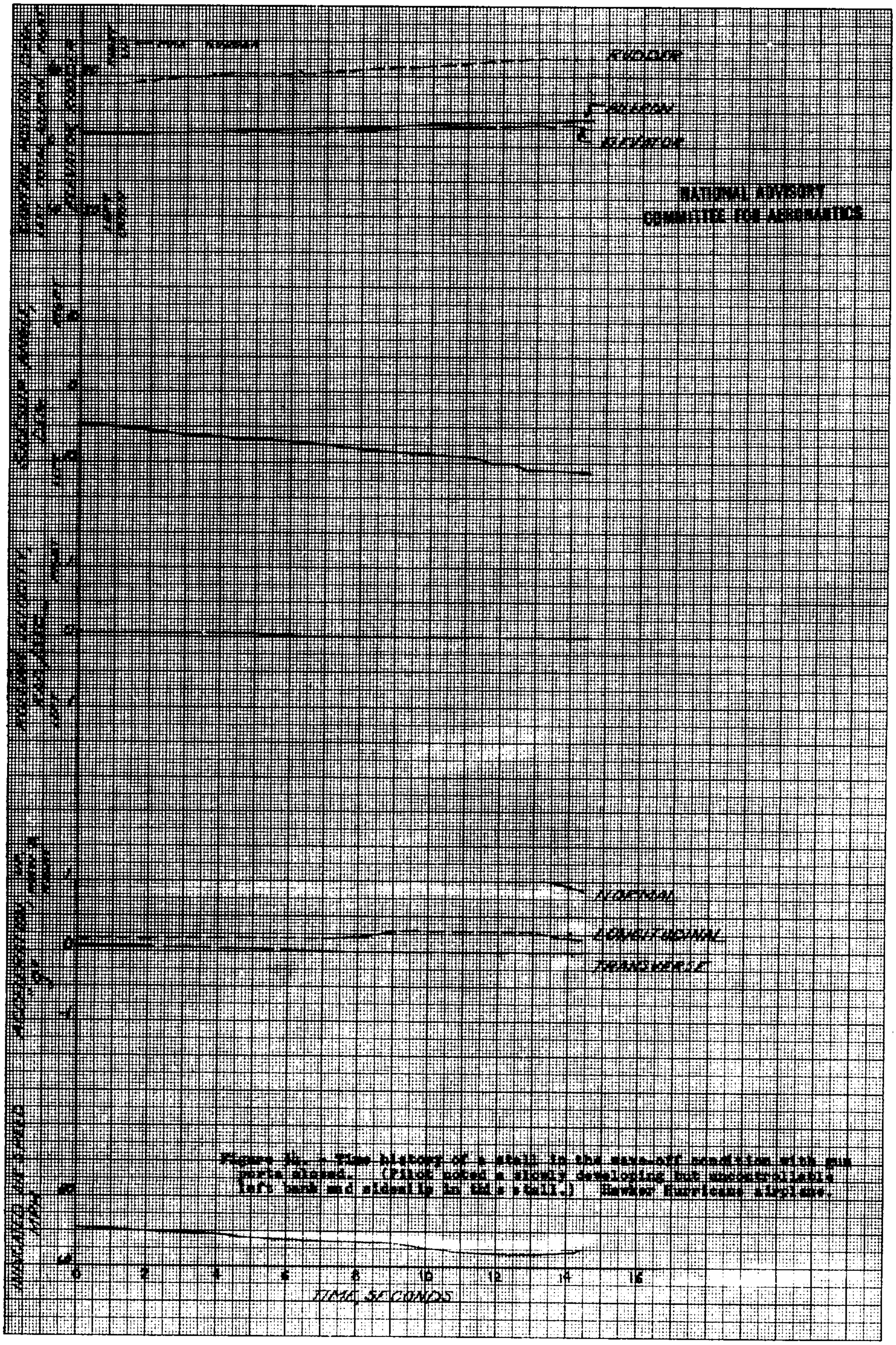

Figure [illegible]. - Time history of a stall in the wave-off condition with gun ports closed. (Pilot noted a slowly developing but uncontrollable left bank and sideslip in this stall.) Hawker Hurricane airplane.